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Benthic Animals as Indicators of Hydrographic Conditions and Climatic Change in Svalbard Waters

R. W. BLACKER

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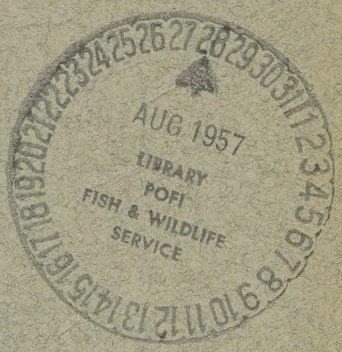
Lowestoft



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A catch of 'Duff' (Geodia) *on board the R.V.* ERNEST HOLT

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CONTENTS

I Introduction . . . . . *page* 1

II The scope and methods of the ERNEST HOLT's benthos survey 2

III Previous work on the benthos of the Area . . . 6

IV The past and present distributions of selected species, their temperature and depth ranges and their reproduction and development 7

1. *Pandalus borealis* 7
2. *Lithodes maia* 9
3. *Sabinea sarsi* and *S. septemcarinata* . . . 11
4. *Sclerocrangon boreas* and *S. ferox* . . . 14
5. *Heliometra glacialis* and *Poliometra prolixa* . . 16
6. *Ceramaster granularis*, *Pseudarchaster parelii* and *Hippasteria phrygiana* 18
7. *Hymenaster pellucidus* and *Lophaster furcifer* . 21
8. *Gorgonocephalus eucnemis*, *G. arcticus*, *G. lamarcki* and *G. caput-medusae* 22
9. *Ophiopleura borealis* 26
10. *Geodia barretti* 27

V The relation between benthos and the hydrographic conditions 29

VI Recent changes in the distribution of benthos in the Area . 34

VII The mechanism producing the changes 35

VIII Conclusion 37

IX Summary 39

X References 39

Appendix 1. Some notes on the identification of the various indicator species 42

Appendix 2. Tables of past occurrences of selected species . 48

Appendix 3. Tables of recent occurrences. 48

Benthic Animals as Indicators of Hydrographic Conditions and Climatic Change in Svalbard Waters

I. INTRODUCTION

In recent years there has been a general warming-up of the Arctic regions, which seems to have begun about 1885 (Willett, 1950). From then until 1917 there was a gradual rise of air temperature, more especially of the winter mean air temperature, in all regions north of 70°N. latitude. Since 1917, in the Arctic the rise has been much sharper, so that by 1938 the winter mean air temperature of Spitsbergen was nearly 6°C. warmer than at the beginning of the century (Hoel, 1953). This warming-up has produced many effects on land and in the sea. On land the recession of glaciers all over the Northern Hemisphere has been one of the features of the change of climate, and in Norway (Ahlmann, 1949) and in Spitsbergen (Heintz, 1950) the recession seems to be continuing. In the sea the change started later. In South Greenland the first signs of warming-up became apparent about 1917 (Jensen, 1939) and the effects spread rapidly northwards in the following decade. In the European Arctic and the Arctic Ocean the change started several years later than in Greenland (Jensen, 1939). Schokalsky (1936) gives 1921 as the year in which marine changes began in the Polar Sea north of Spitsbergen. He and others (Mosby, 1938, and Smed, 1949) have noted the decrease in thickness of the cold surface layer of the Arctic Ocean, and the corresponding increase in temperature and depth of the warm water underlying the cold layer, which have occurred since the voyages of the VØRINGEN (Mohn, 1883) and the FRAM (Nansen, 1902).

As might be expected, the first change amongst marine animals was noticed in the fish population. This was manifest in the reappearance of cod in great quantities on the Bear Island Bank, after an absence of any sustained large quantity for about 40 years. This has subsequently developed into the great Bear Island cod fishery which has been carried on, with the exception of the war years, ever since 1929 (Graham *et al.*, 1954). Some years before, the cod had reappeared at Greenland and a fishery developed there too (Hansen, 1949). The occurrences of various warm-water species of fish at Iceland and Greenland have been recorded by Fridriksson (1949) and Tåning (1949). All these give some idea of the changes which have taken place in the seas, but it is difficult to assess the full extent of these changes from records of highly migratory fish like the cod, which undoubtedly respond to annual variations in the sea, as well as to long-term trends.

Comparatively little attention has been paid to bottom-living animals. Tåning (1949) has noted the northward extension of the ranges of *Asterias rubens* and *Mytilus edulis* at Greenland. Jensen (1939) and Stephensen (1939) quote Saemundsson's notes of the spread from the south and south-west to the north coast of Iceland of *Echinus esculentus*, *Aphrodite aculeata* and *Lithodes maia*, which he attributed to the increase in sea temperatures there since about 1925. Russian scientists have recorded changes in the bottom fauna of the Murman coast and Kola Fjord. Tanasijcuk (1929) gives nine boreal species of benthos which appeared in Kola Fjord for the first time in recent years between 1921 and 1928. He further mentions an increase in numbers of other boreal species (*Echinus esculentus* and *Cardium edule*) which were previously rare in the Fjord. These changes he correlates with an increase of about 1°C. in the mean bottom temperature of the Murman Current for the period 1921–26, when compared with the years 1900–06. These seem to be the only references to recent changes in the benthos. No previous mention seems to have been made of any changes in the distribution of benthos at Spitsbergen although some hydrographic changes have been recorded there and it is there that the warming-up of the land climate has been most marked.

Such changes as have been noted amongst the bottom fauna at Greenland and elsewhere

have usually been ascribed in a general way to the warming-up of the Arctic region Precisely what hydrographic variations can be inferred from these changes in the bentho have not been described. But observations of bottom animals that cannot undertake mor than local migrations, if they can move at all, might be expected to give a better picture c hydrographic conditions than most other types of observation, particularly where continuou records of factors such as temperature are unobtainable. It seems reasonable to suppos that a fully-grown benthic animal must be representative of the predominant hydrograph conditions during its years of growth, but is not necessarily representative of hydrograph conditions recorded at the time of capture. Benthos might, therefore, be expected to giv a reliable picture of the dominant hydrographic conditions, and long-term changes in th hydrography ought to be reflected in changes in the distribution of benthos.

This paper shows in the first place how the distributions of some bottom animals a closely related to hydrographic conditions in the Svalbard* region, where there are on two main types of bottom water, Arctic and Atlantic, each of which has a characteristi range of temperature. The procedure therefore has been to select, from recent record species with limited temperature ranges, in other words stenothermal species, whose tem perature limits correspond to those of either Arctic or Atlantic water, so that they may b fairly called Arctic or Atlantic species. Some measure of confirmation of the designation of these species has been obtained by comparison with others, eurythermal species, whic are not restricted by temperatures within the total range found in the region. From th distributions of the selected indicator species a chart has been drawn of the areas whe Atlantic and Arctic conditions predominate on the bottom at the present time.

The second aim of this paper is to show how hydrographic conditions have changed recent years. This has been done by comparing the chart of present hydrographic co ditions as indicated by the benthos, with a similar chart based on past records of the sam indicator species. To obtain sufficient data from the past, it has been necessary to ac together records from a period of just over 50 years, but this seems to be justified by th very close agreement of individual records throughout the period. How hydrograph changes affect the lives of the indicator species can only be speculated at the present tim but the ultimate effects of these changes, either extension of range or extinction, seem be abundantly proved. This method of assessing hydrographic or climatic change fro benthic indicator species is therefore offered for use in places where continuous records physical factors cannot be obtained.

II. THE SCOPE AND METHODS OF THE *ERNEST HOLT'S* BENTHOS SURVEY

Although benthos was not originally part of the ERNEST HOLT'S programme, inevitably so was caught and records of some species such as the sponge *Geodia* and the prawn *Panda borealis* were kept from the beginning in January, 1949. Later, collecting of specimens fr the fishing grounds around Bear Island was begun by the author. At an early stage in t working up of this material, it became apparent that even around Bear Island some spec had restricted ranges, which seemed to be correlated with different water masses. As la cruises extended the coverage to the north and east, this distinction became much clear showing one group of species confined to the west of Bear Island and Spitsbergen, a another to the east. As the following charts and graphs show, these are Atlantic water a Arctic water species respectively.

By relying on the trawl as the sampling device, it has been possible to obtain samp from a very wide area which could not have been covered in any other way without seriou interfering with the ship's fishing programme. Except when large quantities of fish

* Svalbard is the Norwegian name for Spitsbergen and its neighbouring islands, including Bear Isl and Hope Island.

caught, there is nearly always some benthos in the cod-end or in the shrimp-netting cod-end cover. The shrimp-netting cover was first used during Cruise VII, 1950, and has been used ever since except for occasional hauls when it has been omitted for some special reason. Fig. 1 shows all the positions from which benthos records have been obtained for all cruises

FIG. 1. *Distribution of recent benthos records 1949 to 1955.*

All stations for which there are reliable records of any benthos species are included for all cruises to the region from 1949 to 1953, plus cruises V, 1954, and IV, 1955. The hatched area around Bear Island covers over 100 stations. The names on this chart are those agreed upon at a recent meeting of Norwegian and British scientists. The term 'Area' used throughout this paper, refers to all that part of this chart north of 72°N.

from 1949 to 1953, with the exception of two trips to Greenland, together with stations worked during cruises V, 1954, and IV, 1955, which have been included because they covered places not previously sampled. The hatched area west to south of Bear Island includes over 100 stations, which could not be plotted individually. Although more samples have been obtained around Bear Island than elsewhere, the efficiency of sampling there has been considerably less than, for example, the Hope Island region where there has been less 'interference' from fish, so that large quantities of benthos have been caught in nearly every trawl haul. The stations plotted on Fig. 1 may indicate a single specimen or a large number of specimens of many species. The results are thus purely qualitative, and are based on the presence of different species in different places, and not on presence or absence of a species. Negative points are of little significance, but the number of samples over the whole area does largely make up for the inefficiency of any one haul.

Because of the limited amount of ship's time available, no attempt has been made to carry out any quantitative work on the benthos. None of the usual quantitative bottom samplers, such as the Petersen Grab, is efficient in sampling shrimps and other active crustacea, and the large echinoderms are likely to be too widely separated to be caught quantitatively by grabs. Occasionally, hauls have been made with a $1\frac{1}{2}$ metre Agassiz trawl. This has caught large quantities of the smaller epifaunal species, but few of those species which are caught by the main trawl. No doubt numerous small species show restrictions to Arctic and Atlantic conditions, in the same way as some of the large species, but an immense number of samples would be needed to survey the Svalbard area for these small species.

Many hundreds of species have been identified but the majority of these have not been caught frequently enough to give more than a rough idea of their distributions. For the purpose of this paper a number of species have been selected which have been caught sufficiently often for their distributions to be plotted. One of the main criteria in choosing species has been size, because large animals are less likely to be missed by the trawl than small ones, and are less likely to be overlooked amongst the catch. Thus the Ophiuroid *Ophiopleura borealis* has been caught at only nine stations, but it is of such a size, and occurs in such quantities, that it is most unlikely that it has been overlooked anywhere, so that for this species negative hauls are of considerable value, and a very good indication of its distribution is given by those nine records. On the other hand, negative records of the small shrimps *Sabinea sarsi* and *S. septemcarinata* are of no value, and conclusions can only be based on a comparison of the finds of the two species.

The bottom temperatures given are, except for two hauls, those taken at the end of each trawl haul. (See Graham *et al.*, 1954, Appendix VI.) For the two exceptions, temperatures taken before the haul are used because they are isolated hauls in an important area where no other information is available. For all the stations on Fig. 1 where temperatures were obtained, these bottom temperatures have been plotted against depth in Fig. 2 to give the total temperature and depth range of the ERNEST HOLT'S benthos survey. These two figures provide an important background to the corresponding plottings for each species. As it has not been possible to plot negative information on the charts and graphs for individual species, readers must refer to Figs. 1 and 2 for comparison with the complete coverage of the hauls. It may be assumed that where conclusions are drawn on distribution, full account has been taken of limitations of coverage. The relevant station numbers, temperature and depth data for the ERNEST HOLT'S cruises will be found in Appendix 3. Tables 3 to 17 give the occurrences of all Echinoderms and Crustacea, found during the years 1949 to 1953, while Table 18 gives the finds of *Geodia* during that period. Tables 19 and 20 summarize the finds of the selected indicator species for cruises V, 1954, and IV, 1955.

Throughout the following paragraphs, the term 'Area' has been used to denote that part of Fig. 1 north of 72°N. Lat. South of this latitude insufficient sampling has been done, so that records from south of 72°N. are not included on the distribution charts, except for that of *Geodia*. The western edge of the Area is bounded by the deep water of the Greenland Sea, and no samples have been obtained from depths greater than 265 fathoms. It is to be hoped that at some future date underwater photography may give some

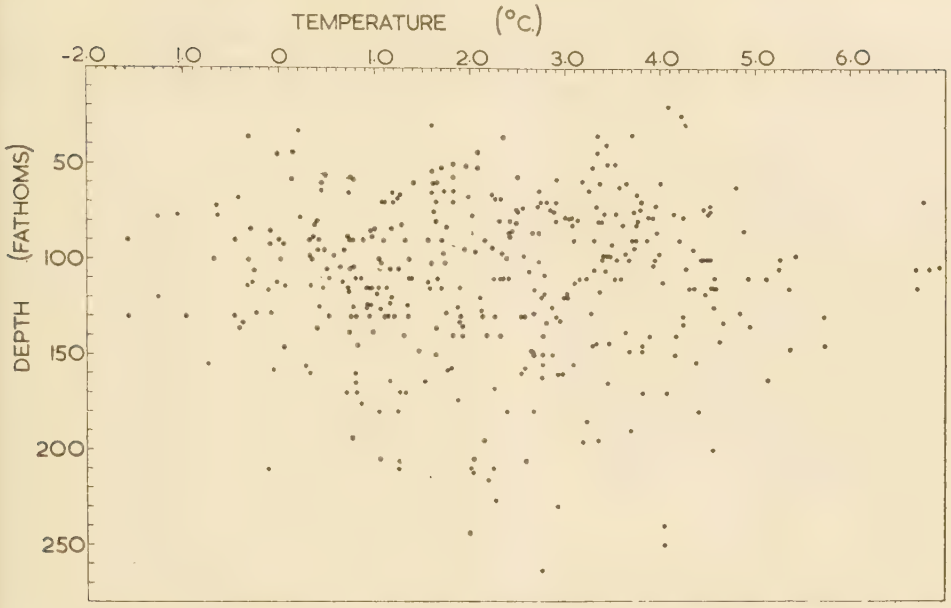


FIG. 2. *Temperature and depth distribution of all benthos stations*
These stations correspond to all those in Fig. 1 for which bottom temperatures are available.

ıformation about greater depths. More data are also required from the northern and ıstern fringes of the Area, from the Bear Island Channel, and from the North Bear Island ıd Storfjord Banks. (These names, shown on Fig. 1, are those recently agreed at a meeting etween Norwegian scientists and the Arctic team of the Fisheries Laboratory, Lowestoft.)

FIG. 3. *Previous work in the Area from 1878 to 1914*
These stations were worked by the VØRINGEN (1878), PRINCESSE-ALICE (1898, 1899), OLGA (1898), MICHAEL SARS (1900, 1901, 1905, 1914) and the Russian Spitsbergen expeditions (1899, 1900, 1901).

III. PREVIOUS WORK ON THE BENTHOS OF THE AREA

There were two periods in the past during which extensive research was carried out in t Area. The first of these was from 1878 to 1914 when a number of mainly oceanograph research voyages were carried out by various nations. The most notable of these were:

1. The Norwegian North Atlantic Expedition in the VØRINGEN during 1878. (Danielsse 1892, Danielssen and Koren, 1884, Grieg, 1893, and G. O. Sars, 1885–86.)

2. The Prince of Monaco's researches in the PRINCESSE-ALICE during 1898 and 18 (Koehler, 1909).

3. The Russian Spitsbergen expeditions in 1899, 1900 and 1901 (Birula, 1907).

4. The German fishery investigations in the OLGA in 1898 (Hartlaub, Döderlein, 190

5. Various visits to the Bear Island region by the MICHAEL SARS during 1900, 19 1905, 1914. (Grieg, 1904, etc.) (Fig. 3 gives the stations worked in the Area by th expeditions.)

Several other expeditions such as the Duc d'Orléans' BELGICA visited the Area duri this period but as their efforts were concentrated on inshore and littoral work they h been included only for their temperature information (Grieg, 1907b, 1910).

The second period of marine research activity was between 1923 and 1931, when t Norwegians carried out a series of fishery research voyages to Svalbard. Although the m purpose of these cruises was to investigate the cod, bottom fauna was collected at so trawl stations and occasionally by dredge. J. A. Grieg of Bergen Museum worked up th

FIG. 4. *Previous work in the Area from 1923 to 1931.*

Stations from which benthos samples were obtained during the Norwegian fishery investigations in the BLAAFJELD (1923), TOVIK (1923, 1924), ARMAUER HANSEN (1926), KIRKHOLMEN (1928), SOTRA (1929, 1930, 1931) and VEIDING (1931). As these include some records from the stomach contents of line-caught fish, a somewhat exaggerated coverage is given, particularly east of Bear Island. For stations plotted thus O, records of Crustacea only are published.

llections for decapod crustacea and echinoderma (Grieg, 1925, 1927a, b, 1931, 1933). In ing so, he included the stomach contents of the fish caught to increase the coverage of s material, without always distinguishing between these and the live material. Fig. 4 ows all the stations for which he gives records of benthic animals, irrespective of whether ey were found alive or in fish stomachs. This gives a somewhat false picture of the mpling of benthos, as far as the present paper is concerned, particularly in the area to e east of Bear Island, because the species included in this paper rarely occur in the diet any fish.

Altogether, however, there seems to be sufficient information from all sources for the hing grounds around Bear Island and off the west coast of Spitsbergen, for a comparison the distribution of benthos during the period 1878–1931 with that of the present day. he data from these cruises are summarized in Appendix 2, Tables 1 and 2.

In addition to the cruises above, upon whose data the benthos distributions for 1878 1931 have been based, one other must be mentioned. In July, 1931, the late J. Armitage obertson of this laboratory made a voyage to Bear Island on a commercial trawler. During is trip, apart from his studies of the fish caught, he collected benthos samples from the awl. This material was worked up for his report (Robertson, 1932), but has not been otted in this paper owing to the difficulties of fixing the positions of his trawl hauls. It ffices to say that his results substantially agree with those found by other investigators uring the same period and earlier.

IV. THE PAST AND PRESENT DISTRIBUTIONS OF SELECTED SPECIES, THEIR TEMPERATURE AND DEPTH RANGES AND THEIR REPRODUCTION AND DEVELOPMENT

the following paragraphs for each species or group of species, all the relative information given. For all the species, except *Geodia*, it has been possible to give a brief note on their tal distribution, most of which have been obtained from the 'Zoology of Iceland', supplemented from various other sources where necessary.

The information about distribution in past years has been obtained from the cruises med above, while recent distribution is based entirely on that obtained on the ERNEST OLT. The temperature/depth graphs of each species are based on the ERNEST HOLT'S cords alone, other sources merely being quoted in the text. (See Appendices 2 and 3.)

1. Pandalus borealis Krøyer

stribution

Greenland to Cape Cod; circumpolar; Behring Sea to Columbia River; Japan; orthern Europe. Depth 20–495 fathoms (Rathbun, 1929).

Stephensen (1939) describes it as 'a mainly boreal species but also found in Arctic ters'.

st distribution

This species was recorded from all over the Area by the earlier expeditions. G. O. Sars 885 86) comments on the gigantic size of specimens caught at Spitsbergen, and the RINGEN recorded it at most stations between north Norway and Spitsbergen. The other peditions also found it everywhere, from the Bear Island Channel, Hope Island Deep, st of Bear Island and Spitsbergen.

esent distribution in the Area (Fig. 5)

As the chart shows, *Pandalis borealis* has been found all over the Area. In many places as been found very abundantly, particularly in the Hope Island Deep, and it may be

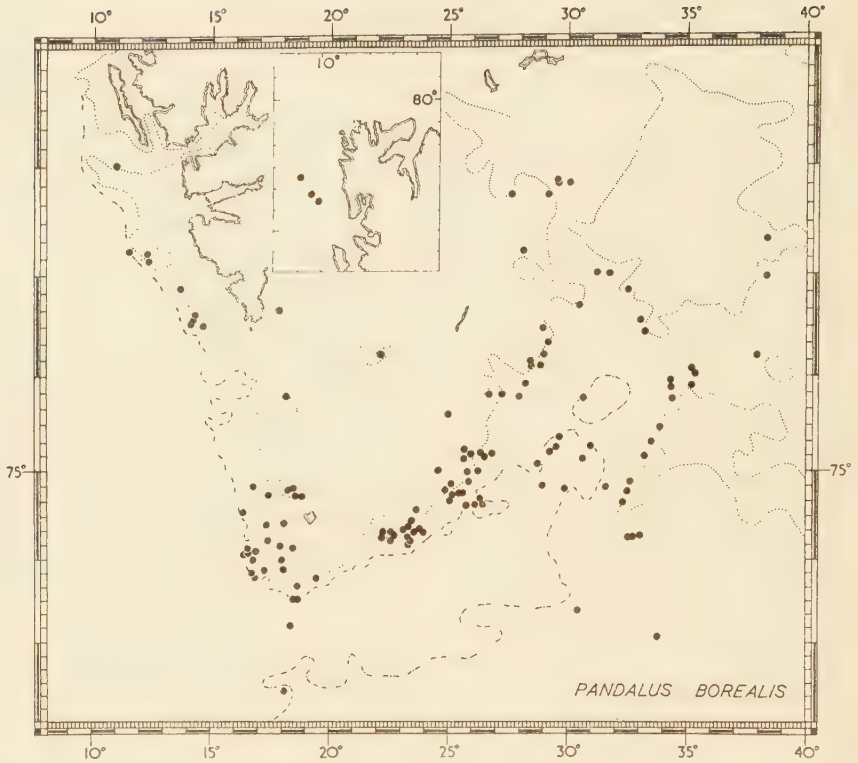


FIG. 5. *Recent findings of* Pandalus borealis.

expected to be equally common in the Bear Island Channel. It is known to be a eurythe species whose distribution contrasts greatly with that of the stenothermal species descri below. It is a protandric hermaphrodite and does show some depth limitations. It has been found in very shallow water on the banks, and in moderate depths, 60–90 fatho juveniles and the smaller males are the only specimens found on the bottom. Large sp mens have occasionally been taken pelagically at depths as shallow as 30 fathoms w

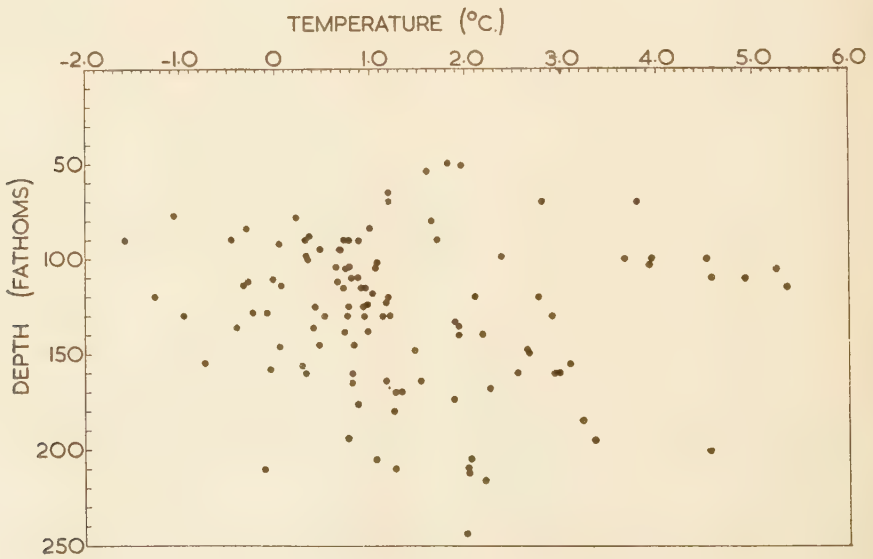


FIG. 6. *Depth and temperature distribution of* Pandalus borealis.

ıe bottom was at 120 fathoms, but usually they have been found only in deeper water, here they often form a large part of the diet of the cod.

This species has shown no great change in its distribution since the earliest records om the Area, as would be expected of a species which has no marked temperature reference.

emperature depth range

Fig. 6 shows the temperature and depth range for all the ERNEST HOLT's records of *andalus borealis*. It has been found in all temperatures from −1·58°C. to +5·35°C. and anges in depth from 50 to 244 fathoms. This shows conclusively that it is a eurythermal pecies, and confirms the earlier findings. Hansen (1908) quotes records from −1·8°C. to +7°C., and gives the Danish INGOLF Expedition's findings as ranging from −0·6°C. to +6·5°C. The MICHAEL SARS found this species in temperatures varying from −1·15°C. o 6·4°C.

Reproduction and development

Pandalus borealis is a protandric hermaphrodite and like most other prawns it has a elagic larva, which is well known.

2. LITHODES MAIA (Linnaeus)

Distribution

'A mainly boreal species found in the northern part of the Atlantic, from about 40°–8°N. Lat. on the western side to about 45°–75°N. on the European side; the depths are rdinarily ca. 100–200 m. It was never found at temperatures below 0°C.' (Stephensen, 939).

At Iceland it is recorded as common on the south and west coasts, and as rare on the orth-west, north and east coasts.

Rathbun (1929) gives its depth range as 35–291 fathoms.

Past distribution in the area (Fig. 7A)

This crab was recorded by several of the earlier Arctic research expeditions, as occurring ıear Bear Island. All these records are from the edge of the shelf west of the island. Although there is one note of a find of this crab at Spitsbergen (Hofsten, 1916), this ctually refers to the Spitsbergen Bank and is one of the findings near Bear Island. It is nost unlikely that this species was overlooked as the investigators were all familiar with the pecies from elsewhere. It may therefore be assumed to have been absent from Spitsbergen.

Present distribution in the Area (Fig. 7B)

Lithodes has frequently been taken by the ERNEST HOLT, always along the slopes of the vestern edge of the Area. A recent cruise (VI, 1955), which it has not yet been possible to vork up fully for inclusion in the tables and charts, found this species as far as 79°N. In ontrast to its previous absence, it is now comparatively abundant at Spitsbergen, six or nore large specimens often being caught in a trawl haul, and it has been found in shallower vater there (44 fathoms) than at Bear Island. It has never been found east of Bear Island.

Comparison with earlier records shows that this species has spread from 75°N. to 79°N. at. – over 200 miles further north in the past 25 years or so. This is paralleled by its ccurrence at Iceland, of which Stephensen (1939) quotes Saemundsson as writing in 936: 'It seems to be not rare in the warmer and deeper water off the south and west coast, nd in the last 2–3 years it seems to have moved eastwards, along the north coast, where t was unknown before 1930. This supposed eastward moving of the animal should, in my pinion, be due to the increasing temperature of the water along the north coast in the ast years.' The temperature data below show that this is undoubtedly a warm-water nimal, so that its great northward spread may be attributed to an increase in the influence f the warm water West Spitsbergen Current along the western edge of the Area.

FIG. 7. *Distributions of* Lithodes mai Poliometra prolixa, Heliometra glacial *and* Ophiopleura borealis. *A. Past record B. Recent records.*

Note how *Heliometra* and *Poliometra* have disappeared west of Spitsbergen, where *Lithodes* is now found. *Poliometra* has not yet been taken in the Area by the ERNEST HOLT, and there are no past records of *Ophiopleura* except from inshore waters east of Spitsbergen.

Temperature and depth range (Fig. 12)

The ERNEST HOLT records show that it is rare in water below 2·5°C., as only three records are from below that temperature. The two records from 0·5°C. and 1·3°C. must be considered exceptional, most probably being due to cold water cascading over the continental slope. The depth range for the Area is slightly less than for its world range, 4–200 fathoms against 35–291 fathoms, but the deeper parts of the Area have not been sampled exhaustively, so its depth range in the Area may extend to deeper than 200 fathoms. In the absence of any permanently warm shallow water in the Area, it is unlikely to be found any shallower than the 44-fathom find.

Temperature data from elsewhere are scarce. Hansen (1908) merely states that it was never found in temperatures below zero. Grieg (1927b) gives temperatures of 6·15°C. and 7·5°C. for two of the MICHAEL SARS records, but none are given for the earlier records from the Area.

These temperature records together with the distribution chart show that *Lithodes* is confined to Atlantic water.

Reproduction and development

Little is known about the development of this species. Only two specimens of egg-bearing females have been taken by the ERNEST HOLT, both from Bear Island, one in early December and the other at the end of April. From the west coast of Norway they have been recorded from early December to early March, and the latest planktonic larval stage in April. It is probable therefore that the breeding season is in the winter months, which would explain the absence of egg-bearing females from the samples at Spitsbergen, all of which come from the months of July to October. It is reputed to have a shortened pelagic life and no larval stages have been taken in the ERNEST HOLT'S plankton samples.

3. SABINEA SARSI Smith AND SABINEA SEPTEMCARINATA (Sabine)

Distribution

S. sarsi: Newfoundland to Gulf of Maine, Davis Strait, Iceland, northern Europe. Depth range 40–388 fathoms (Rathbun, 1929).

There are records from Iceland (Stephensen, 1939) from the north-west, north, east and south coasts, mainly from deep water. Stephensen writes of it: 'a boreal species rare under Arctic conditions'.

S. septemcarinata: Mouth of St. Lawrence River to Massachusetts Bay, Arctic Ocean and northern Europe. Depth range 5–133 fathoms (Rathbun, 1929).

At Iceland it is common on the north and east coasts and rare on the north-west. Stephensen (1939) records it as a circum-Arctic species.

East distribution (Fig. 8A)

Records of these two shrimps are scarce, except for Bear Island and the inshore waters round Spitsbergen. Apart from a single record of a newly-settled juvenile from Spitsbergen, *Sabinea sarsi* was found only west of Bear Island. *S. septemcarinata* was better known, and was found around Bear Island, the Hope Island Banks, at a number of places in Storfjord and in the fjords on the west coast of Spitsbergen. Nearly all these records of *S. septemcarinata* are from definitely Arctic conditions.

Present distribution (Fig. 8B)

Both species have been taken at numerous stations by the ERNEST HOLT, often one or the other occurring in large numbers. Around Bear Island there is a certain amount of overlapping of their ranges, mostly in relatively shallow water (50–70 fathoms) where juveniles of both species occur in some numbers. In deeper water west of Bear Island and off the west coast of Spitsbergen *S. sarsi* predominates and *S. septemcarinata* is rare. In colder conditions to the eastwards *S. septemcarinata* becomes more numerous and entirely replaces *S. sarsi*. At Hope Island catches of 100 or more *S. septemcarinata* are quite common, but *S. sarsi* has never been found there.

FIG. 8. *Distributions of* Sabinea sar*and* S. septemcarinata. *A. Past record B. Recent records.*

The single past record of *S. sarsi* at 78°N. refers to a newly settled juvenile. The spread of this species as far as 78°N. is in fact a recent occurrence. Note also the records of *S. sarsi* east of Bear Island which correspond with the spread of *Geodia* in that direction (see Fig. 17).

The temperature records below show that *S. sarsi* is almost completely confined to water with temperatures above 1·75°C. Its lower temperature limit is a little lower than that of *Lithodes*; but the similarities of their distributions show that *S. sarsi* is also a pronouncedly Atlantic species. *S. septemcarinata* is equally definitely an Arctic species. Like *Lithodes*, *S. sarsi* has spread a long way to the north. Owing to lack of records from the past it is impossible to say whether *S. septemcarinata* used to be common on the fishing grounds west of Spitsbergen, but it is very rare there now.

One feature of particular interest is the occasional finding of *S. sarsi* on the southern edge of the Hope Island Banks. In this same area another Atlantic species, the sponge *Geodia*, also occurs in small numbers, which indicates that there must be a considerable Atlantic influence there, which may be increasing. It is unfortunately not yet known what conditions prevail in the deep water south of that region.

Temperature and depth range

Recent records (Fig. 9) show that *S. sarsi* must be considered as rare in temperatures below 1·75°C., or to be more correct, perhaps, temperatures below 1·75°C. should be considered exceptional where *S. sarsi* is found. Conversely, except in relatively shallow water, *S. septemcarinata* is usually found in water below 1·5°C. In depths below 80 fathoms there is little if any overlapping of the two species. As far as depth is concerned, *S. septemcarinata* has been found over the whole range of depths where the bottom temperatures have been about 1°C. or less (see Fig. 2), namely 33–205 fathoms; the latter depth is 25 fathoms deeper than any previous finding of this species. *S. sarsi* has been taken in depths ranging from 50–173 fathoms compared with a known range of 40–388 fathoms elsewhere, but at some of the deeper stations worked by the ERNEST HOLT this species may have been overlooked.

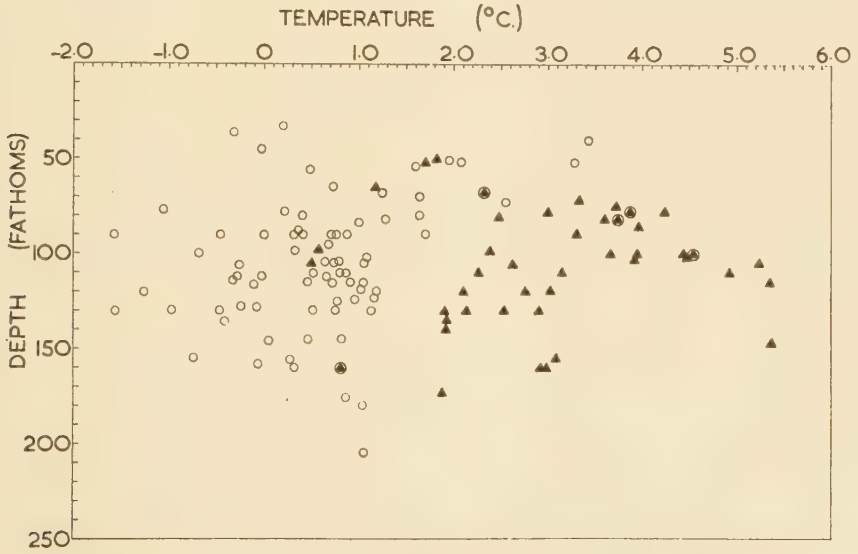


FIG. 9. *Temperature and depth distributions of* Sabinea sarsi (▲) *and* S. septemcarinata (○).

Earlier temperature records give a few exceptional records for *S. sarsi*. Hansen (1908) gives two records from the Faroes of −0·4°C. and 0°C. and one from north-west Iceland of −0·75°C. However all these are from stations at the boundary of cold and warm water masses. Hansen gives three other, more normal temperature records for this species, namely 1·6°C., 6·5°C. and 2·9°C. The few earlier records from the Area are all from about 2°C. In addition, the MICHAEL SARS found *S. sarsi* in 3·98°C. west of the Faroes, and once from Porsangerfjord in −1·15°C., where it was found together with *S. septemcarinata*. Past temperature records of the latter are also scarce. It was taken by the MICHAEL SARS in water varying from −1·15°C. to 4·2°C., but was not found at all by the INGOLF expedition.

Hansen (1908) merely states that it is 'a pronouncedly Arctic form' which is confirmed l recent findings. He writes of *S. sarsi* 'that it is not so distinctly an Arctic species *S. septemcarinata*', which is rather an understatement. Stephensen's reference to it as boreal species rare under Arctic conditions' describes it exactly.

Reproduction and development

Both species have pelagic larvae, which it seems to be impossible to separate, so th plankton records of these are valueless when studying the distribution of the species. Eg bearing females of *S. septemcarinata* have been found in all months from April to Decembe As the region where it is most abundant has not been investigated during the remainir months of the year, it is possible that it breeds at any time during the year. *S. sarsi* h been found with eggs during March and August at Bear Island and October at Spitsberge In the southern Barents Sea, berried females were found in February. It is probable ther fore that neither of these species has a restricted breeding season.

4. Sclerocrangon boreas (Phipps) (=Crangon boreas) and S. ferox (Owen) (=S. salebrosus)

Distribution

Sclerocrangon boreas: 'Labrador to Cape Cod; east and west Greenland, Arctic Ocea Arctic Alaska to Aleutians and north-east Siberia. Depth 0–140 fathoms.' (Rathbun, 192

At Iceland (Stephensen, 1939) it is common on all coasts except the southern, usually shallow water.

Sclerocrangon ferox. Sars (1885–86) found this species at Spitsbergen and records further distribution as from the Kara Sea to the Bering Strait. It is also known from J Mayen, east Greenland and Baffin Bay, so it appears to be a circumpolar cold-water specie Bathymetrical distribution, 50–532 fathoms.

Not known from Iceland.

Past distribution in the Area (Fig. 10A)

S. boreas was widely distributed over the whole area, being recorded from north a west of Spitsbergen, Bear Island and Hope Island. The distribution of *S. ferox* is less w known for the period from 1878 to 1931. There are several records of this form from t west of Spitsbergen, one from the Storfjordrenna and two others from Hope Island.

Present distribution (Fig. 10B)

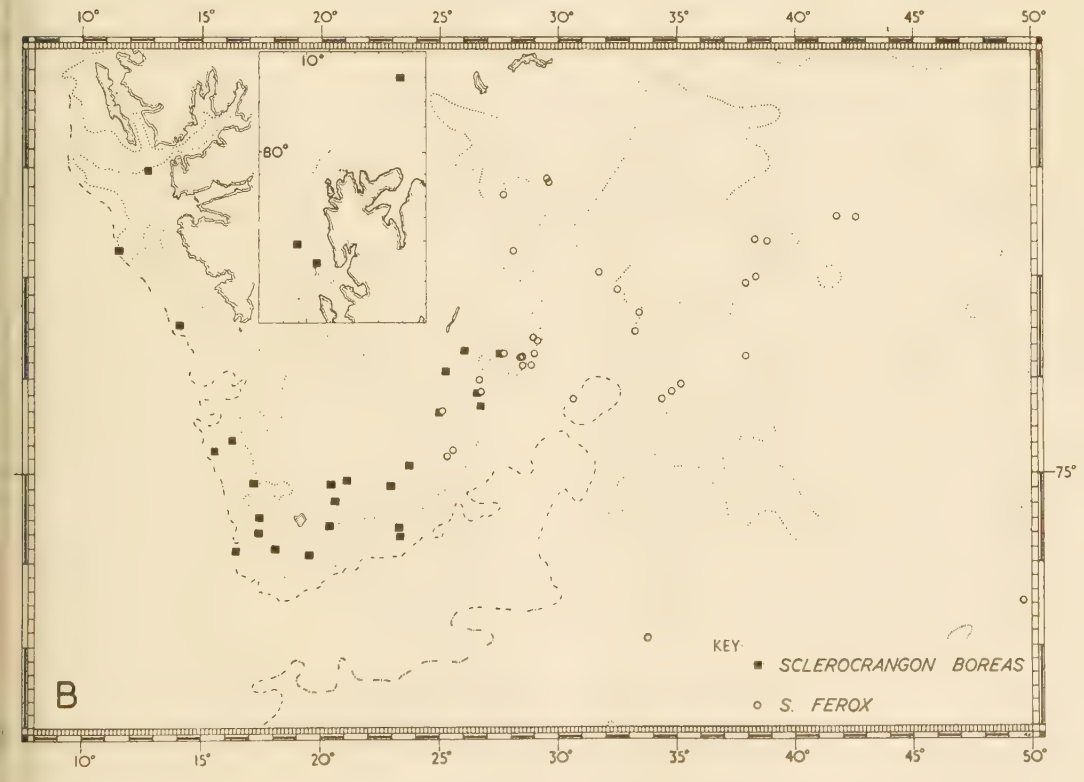
Both these large shrimps have been taken frequently by the ernest holt. On the Ho Island Banks the two species occur together, but nearer Bear Island and at Spitsberg only *S. boreas* has been found. On the Central and Great Banks, in more uniformly c conditions, only *S. ferox* has been found. From this distribution it is clear that *S. ferox* an Arctic species, and the recent temperature records show that it has not been found water warmer than 1°C. This species has not been found west of Spitsbergen in rece years so it has probably disappeared from there like other Arctic forms. It is probably st to be found in Storfjord and Storfjordrenna. In contrast to *S. ferox*, *S. boreas* is widespre over the Area, being found west of Bear Island and Spitsbergen, as well as on the Ho Island Banks. It has been found in temperatures varying from −1·58°C. to 5·35°C., t total temperature range for the Area. It is thus a eurythermal form and, as might expected, since it has no planktonic larval stage, its distribution has remained unchang throughout the past 75 years, in spite of the change of hydrographic conditions which h affected many other species.

Temperature and depth range (Fig. 11)

The recent records give a temperature range for *S. boreas* from −1·58°C. to 5·35°C which agrees closely with the michael sars findings which range from −1·15°C. to 4·5°

FIG. 10. *Distributions of* Sclerocrangon boreas *and* S. ferox. *A. Past records. B. Recent records.*

Note how the distribution of *S. boreas* has remained unchanged, showing that it is an eurythermal species, while *S. ferox* which is restricted to Arctic conditions, is not now found off west Spitsbergen.



Hansen's INGOLF records range from 0·2°C. to 5·6°C. These all show that this is a eury thermal species, but the depth data show that it is much more common in depths shallowe than 100 fathoms, so that its distribution may be partially limited by depth. The greates depth at which the ERNEST HOLT has caught this species is 160 fathoms, which is 20 fathom deeper than any previous record.

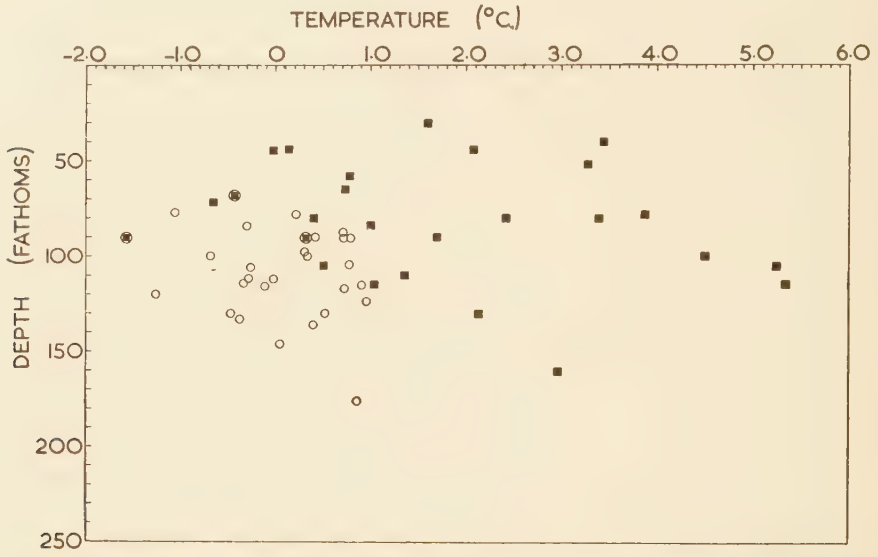


FIG. 11. *Temperature and depth distributions of* Sclerocrangon boreas (■) *and* S. ferox (○).

S. ferox on the other hand shows a distinctly limited temperature range, namel −1·58°C. to 0·96°C. Apart from one or two specimens from temperatures of 1·1°C. a other records fall within the range given above. *S. ferox* must therefore be considered a an Arctic species restricted to water temperatures of 1°C. and below. Its depth range in th Area, of 68–176 fathoms, is considerably less than its total known range of 50–532 fathom but few hauls have been made in deeper water where such low temperatures are likely t be permanent. Similarly it has not been found in as shallow water as elsewhere, becaus nearly all the shallow water in which fishing has been carried out varies widely in tem perature between summer and winter.

Reproduction and development

Both species have very large yolky eggs, which hatch at a very late stage, after meta morphosis has taken place. After hatching, development is direct and the young remai attached to the female's pleopods. There is no pelagic phase. Females of *S. boreas* bearin eggs have been taken in the Area from May to October, which may indicate that it breed in summer, but few samples of it have been taken at other times of the year. Egg-bearin females of *S. ferox* have been found in May, August and September, but in view of it small temperature range there seems to be no reason why this species should have restricted breeding season. If samples could be obtained from the other months of the yea no doubt breeding females would be found. As this species is found in the abyssal regior of the Norwegian and Greenland Seas, where the temperature stays uniformly cold, would not be expected to have a special breeding season.

5. HELIOMETRA GLACIALIS (Leach) (=ANTEDON ESCHRICHTI) AND POLIOMETRA PROLIXA (Sladen) (=ANTEDON PROLIXA)

Distribution

Heliometra glacialis: Arctic seas southwards to Cape Cod, south-west Iceland (or record from deep water) and Finmark. Vertical range: about 10–1350 m.

At Iceland: 'confined to the east and north coasts' (Einarsson, 1948).

'In British seas, occurs only in the cold area of the Faroe Channel. It is an Arctic species, probably of circumpolar distribution, the form occurring in the North Pacific being only regarded as a separate variety' (Mortensen, 1927).

Poliometra prolixa: 'An Arctic species ranging from west and east Greenland to the Kara Sea and as far south as the cold area extends. Known bathymetrical range 24–1960 m.' (Mortensen, 1927).

Previous distribution in the Area (Fig. 7A)

From previous research cruises the Crinoid *Heliometra* is known to have occurred south-east, south and west of Bear Island and northwards along the whole of the west coast of Spitsbergen where it was very abundant (Hartlaub, Döderlein, 1900). The records of Robertson (1932) and those of the Norwegian investigators in the years immediately before then, showed that *Heliometra* still occurred at Bear Island, but it is never mentioned as being abundant there. East of Bear Island there were few records, but as *Heliometra* is still abundant on the Hope Island Banks, there is no reason to doubt that it was common there in the past.

Poliometra was found at various places off the west coast of Spitsbergen, and at Hope Island, and there is also one record from south of Bear Island.

Present distribution (Fig. 7B)

Of these two Crinoids, only *Heliometra* has been found in the Area in recent years. Although large numbers of Crinoids have been examined, *Poliometra* has not been found amongst them. *Heliometra* has been found abundantly on the Hope Island, Central and Great Banks where Arctic conditions prevail, and also on the Storfjord Bank. West of Spitsbergen it has only been found once south of Isfjord, in very shallow water close to the entrance of the fjord. It is almost certain to occur in shallow water further south, particularly near the entrances to the fjords. North of 79°N. it is abundant on the banks, mostly in depths shallower than 100 fathoms.

Comparison of the two charts shows that in recent years these Crinoids have disappeared from banks where *Lithodes* has now been found for the first time. The

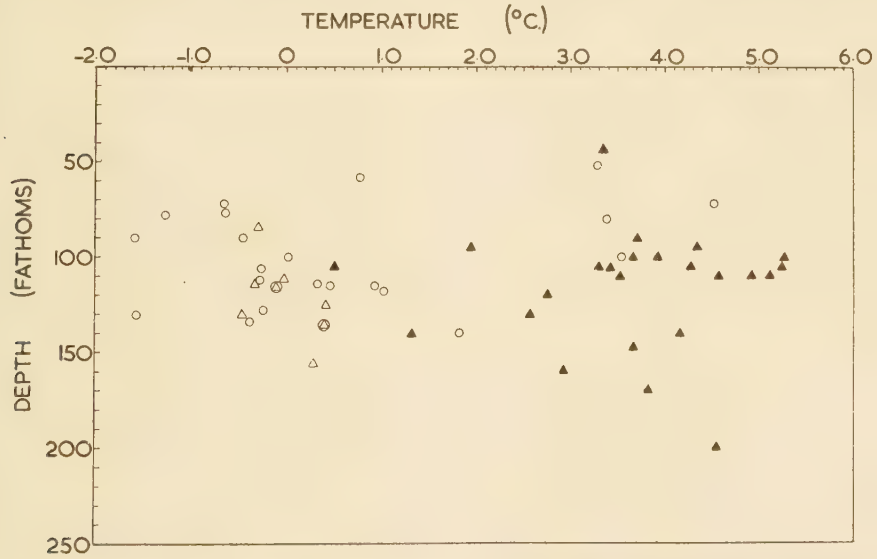


FIG. 12. *Temperature and depth distributions of* Lithodes maia (▲), Heliometra glacialis (○) *and* Ophiopleura borealis (△).

The main temperature range of *Lithodes*, 2·5° to over 5°C. corresponds with the range of bottom-temperature of Atlantic water in the Area. *Heliometra* and *Ophiopleura* are both normally found in Arctic water with temperatures below 1°C. The four exceptional records of *Heliometra* from water over 3°C. are of particular interest because they are all from north of Spitsbergen where Arctic conditions must normally prevail.

temperature data below show at once that this change can be correlated with differences the hydrographic conditions. *Lithodes* is rare in water of less than 2·5°C. while *Heliomet* is equally rare in water over 1°C., which indicates that in recent years Atlantic conditio must have replaced the Arctic regime which prevailed before 1930.

Temperature and depth range

Koehler (1927) gives a temperature range for *Poliometra* of −1°C. to +1°C. *Heliometr* he states, normally lives in water below 1·6°C. but can tolerate water of 3°C. These figur are presumably based on those obtained by such expeditions as those of the INGOLF (Clark 1923) and VØRINGEN (Danielssen, 1892). The former found *Poliometra* in temperatur from −0·8°C. to 1·2°C., and the latter in −2·1°C. to 1·1°C., all but 4 of 17 records bei from below zero. Similarly of the nine findings of *Poliometra* by the MICHAEL SARS (Grie 1905), which vary from −1·0°C. to +1·03°C., only two are from water above 0°C. *Poli metra* is thus rare in water with temperatures above zero.

Heliometra seems to withstand slightly higher temperatures than *Poliometra* but it rare to find water temperatures above 1°C. where this species occurs. The VØRINGEN four it in bottom water temperatures ranging from −1·2°C. to +1·1°C. In addition to tv stations merely referred to as 'the cold area of the Norwegian Sea', Grieg gives for th MICHAEL SARS records of *Heliometra* a range from −0·69°C. to 1·1°C. with three somewh warmer records, namely 2·1°C. and 2·3°C. for two findings near Bear Island, and 3·12° for one on the Faroe-Iceland ridge. All three are from areas near the boundary of cold a warm waters. *Heliometra* was not found commonly anywhere during the INGOLF expeditio the only complete specimens being found in water of −0·4°C. and +0·5°C., while the were two records of fragments from 3·5°C. and 5·5°C.

Recent bottom-temperature records, as shown in Fig. 12, confirm that the usual ter peratures where *Heliometra* is found are below 1°C. The four records from over 3°C. a of interest because they are from north Spitsbergen. One of them from the entrance Isfjord is obviously not far removed from cold water. The abundance of *Heliometra* the banks north of 79°N. must indicate that these banks are usually covered by Arct water and that such warm temperatures are very unusual there. If, however, the wat stays warm, as it might do if the present conditions in Arctic climate persist, then it almost certain that *Heliometra* will disappear from these northern banks as it has done fro those further south.

Reproduction and development

As for most of the Arctic echinoderms, *Heliometra's* reproduction and developme are little known. It is believed to have free eggs and a planktonic larva like those Crino whose reproduction method is known. The larva presumably metamorphoses into a pent crinoid stage on the bottom. A few specimens of a pentacroid stage, probably of *Heliometr* have been found by the ERNEST HOLT in the Hope Island Deep. The reproduction *Poliometra* is also unknown, but it too probably has free eggs and pelagic larvae. T development of its pentacrinoid has, however, been described by Mortensen (1910).

6. CERAMASTER GRANULARIS (O. F. Müller) (=PENTAGONASTER G.), PSEUDARCHASTER PARELII (Düben & Koren) (=ARCHASTER P.) AND HIPPASTERIA PHRYGIANA (Parelius) (=H. PLANA)

Distribution (*Einarsson*, 1948)

Ceramaster granularis: 'From Finmarken to Skagerrak; further off Morocco and t Azores. From W. Greenland to 41°N. Lat. on the east coast of N. America. Vertical rang 20–1400 m.'

At Iceland: 'seems confined to the slope where the influence of Atlantic water prevail

Pseudarchaster parelii: 'From the Murman coast along the Scandinavian coast to and W. Ireland. From S. Greenland to 38°N. Lat. along the east coast of N. Americ Vertical range, 15–2500 m.'

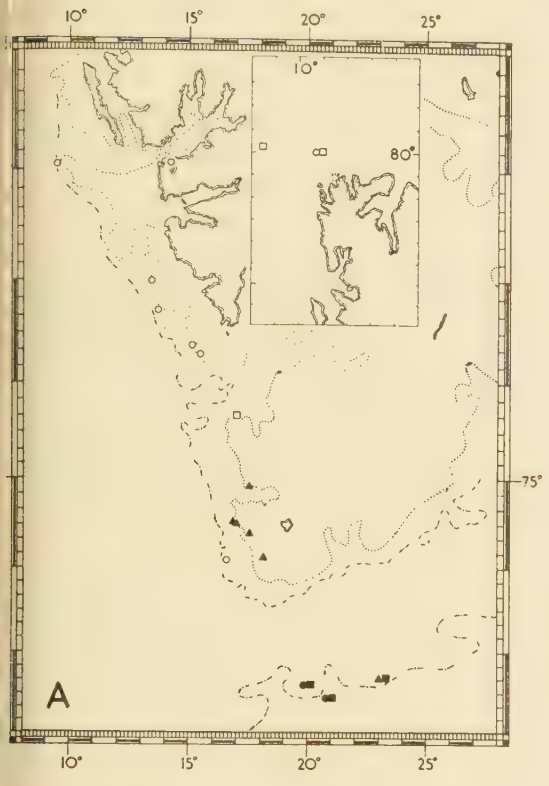


FIG. 13. *Distributions of* Ceramaster granularis, Pseudarchaster parelii, Hippasteria phrygiana, Hymenaster pellucidus *and* Lophaster furcifer. *A. Past records. B. Present records.*

Like *Lithodes*, *Hippasteria* has spread from Bear Island to at least 77°N. off west Spitsbergen, while *Lophaster* has disappeared from there. Both the latter and *Hymenaster* have in recent years only been taken in pronounced Arctic conditions east of Bear Island. *Ceramaster* now occurs near Bear Island whereas previously it had only been found south of the Bear Island Channel, but *Pseudarchaster* has not spread northwards, which may mean that it does not produce a planktonic larva and so is unable to extend its range rapidly.

At Iceland: 'has only been found on the slope, where warmer Atlantic water is found

Hippasteria phrygiana: 'From Finmarken to Kattegat. From W. Greenland to 42°N Lat. along the east coast of N. America. Vertical range, 20–800 m.'

At Iceland it is known from all coasts except the north-east.

'In British seas it has been recorded from Plymouth Sound, Cornwall, the west and east coast of Scotland down to Northumberland; also from the Rockall Bank' (Mortensen 1927).

Past distribution in the Area (Fig. 13A)

Both *Ceramaster* and *Pseudarchaster* were restricted to the area south of the Bear Island Channel and to the Finmark and Murman coasts. *Hippasteria* was also recorded from this area, and in addition it was found a number of times west of Bear Island. Robertson (1931) writes: '*Hippasteria* was frequently present in the trawl but were of such size that I could only preserve the smallest.' None of these species was found where Arctic conditions predominated. Appellöf (1912), commenting on the boreo-arctic nature of the fauna of the Finmark and Murman coasts, states that it '. . . includes littoral and deeper-living boreal forms that are never met with at Spitsbergen . . . (one of the best-known areas in high Arctic latitudes)'. *Hippasteria* and *Ceramaster* are included in the list of boreal forms to which he was referring.

Present distribution (Fig. 13B)

The present distributions of these three boreal species show some interesting features. *Pseudarchaster* has merely maintained its former distribution, and has not yet been found north of the Bear Island Channel, but the other two have greatly extended their range. *Ceramaster* has now been found occasionally at Bear Island, over 100 miles further north than it was previously known. *Hippasteria* has extended its range even further, so that it is now found off the west coast of Spitsbergen as far as 77° 30′N., nearly 200 miles beyond its previous northernmost occurrence.

These great extensions of distribution are similar to those found for *Lithodes* and *Sabinea sarsi*. Like *Lithodes*, *Hippasteria* is rare in water of less than 2°C. In other words it too is an Atlantic species, and its northern spread must have been caused by an increase in the influence of Atlantic water off Spitsbergen.

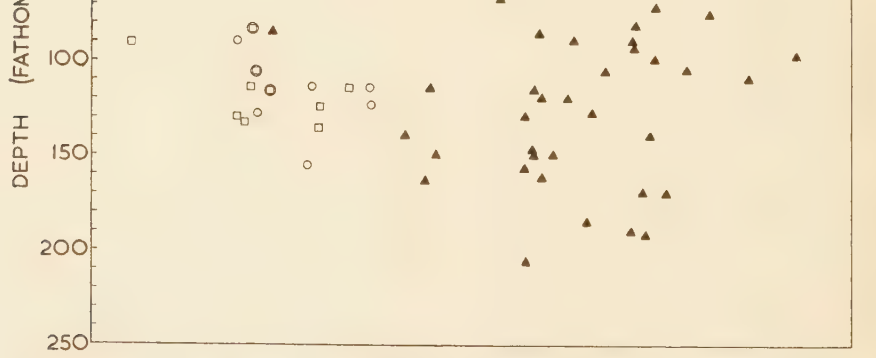


FIG. 14. *Temperature and depth distributions of* Hippasteria phrygiana (▲), Hymenaster pellucidus (□) *and* Lophaster furcifer (○).

Both *Hymenaster* and *Lophaster* have not been taken in temperatures above 1°C. and are clearly Arctic species. *Hippasteria* is mainly restricted to temperatures above 2°C., so the −0·1°C. record is probably due to cascading cold water, while the other records from less than 2°C. are from mixed Arctic and Atlantic water west of Bear Island.

emperature and depth range

The temperature/depth chart for *Hippasteria* (Fig. 14) shows at once that it is rarely und in water below 2·5°C. The one record from bottom-water with a temperature of ·0·09°C. must obviously be due to cold water cascading off the banks, through the area fluenced by West Spitsbergen Current. The few other records from water below 2°C. e from places where the mixing of Arctic and Atlantic water takes place. Other tem- erature records confirm that *Hippasteria* is an Atlantic form. Danielssen and Koren (1884) und it twice, in temperatures of 1·9°C. and 3·5°C., while Grieg (1907a) for the MICHAEL RS records gives only two below 3°C. in a range from 1·6° to 8·71°C. The restriction of e range of *Hippasteria* cannot be due to depth, as its depth range in the Area, of 60–206 thoms, is well within its total known depth-range of 11–440 fathoms. The other two ecies have similar temperature ranges, although *Pseudarchaster* is possibly restricted to mewhat higher temperatures than the others. The records for *Pseudarchaster* are: ØRINGEN (Danielssen and Koren, 1884), 1·9°, 2·8°, 3·5°, 6·0°, 6·9° and 7·2°C.; MICHAEL RS (Grieg, 1907a), 6·34°C.; ERNEST HOLT, 4·54°C. There are a few more figures for *eramaster*. The VØRINGEN findings vary from 1·9°C. to 5·1°C. and the MICHAEL SARS from 6°C. to 3·98°C., most of them being over 3°C. The ERNEST HOLT has only two records, 07°C. and 2·92°C. The former, which must be considered exceptionally low, is from latively shallow water near Bear Island, where mixing of Arctic and Atlantic water takes lace. The total depth ranges of *Pseudarchaster* and *Ceramaster* are respectively 8–1370 thoms and 11–765 fathoms, so their distributions are unlikely to be restricted on account f depth alone.

eproduction and development

Little is known about the biology of any of these species. Both *Hippasteria* and *Cera- aster* have large yolky eggs from which it has been inferred that they develop directly, resumably through a lecithotrophic pelagic larval stage and not, as Mortensen (1927) pposes, without a pelagic stage. The great spread of these species in such a short time nows that they must have a pelagic phase in their life histories. Nothing is known about ne reproduction of *Pseudarchaster*, but the fact that it has not spread northwards like ther Atlantic species may mean that it does not have a pelagic larva.

7. HYMENASTER PELLUCIDUS Wyv. Thomson AND LOPHASTER FURCIFER (Düben & Koren) (=SOLASTER F.)

istribution

Hymenaster pellucidus: '. . . Norwegian Sea to Spitsbergen and east Greenland and to ne Siberian Sea. In British seas . . . only from the Faroe Channel, the cold area, 1045 m. . . . the species being rather exclusively a cold-water form. Bathymetric distribution a. 15–2800 m.' (Mortensen, 1927).

At Iceland: '. . . was found only on the deeper clay bottom off the north coast' (Einar- son, 1948).

Lophaster furcifer: 'In British seas . . . only from the cold area of the Faroe Channel, nd from the Lousy Bank . . . elsewhere from Stavenger on the Norwegian coast to Spits- ergen and the Siberian Sea, and from Greenland to 40°N. on the American coast. Bathy- netrical distribution ca. 30–1350 m.' (Mortensen, 1927).

From Iceland there are only two records, both from deep water off the east coast Einarsson, 1948).

revious distribution in the Area (Fig. 13A)

Although these species were not found very often, the few records that exist show that hey had distributions similar to those of *Heliometra* and *Poliometra* along the west and orth coasts of Spitsbergen. Only *Lophaster* was found at Bear Island, and that record efers to a single juvenile of 3 mm. radius. No records exist for the area east of Bear Island, resumably because of poor sampling.

Present distribution (Fig. 13B)

All the recent occurrences of these species are from the area east of Bear Island, on th Hope Island, Central and Great Banks. *Hymenaster* has also been found in the Hope Islan Deep. *Lophaster* has nearly always been found where large numbers of *Heliometra* hav been caught. The temperature data show that *Hymenaster* and *Lophaster* are only foun where Arctic conditions predominate and like the other Arctic forms, *Heliometra* an *Poliometra*, they have both disappeared from the west Spitsbergen fishing grounds.

Temperature and depth ranges

Depth, as a factor directly influencing the distributions of these two species, may b discounted by a comparison of their depth ranges in the Area, with those for their tota distribution. Thus *Hymenaster* has been found in the Area in depths ranging from 84 t 156 fathoms, and elsewhere in 8 to 1530 fathoms. The corresponding figures for *Lophaste* are 84–136 and 16–740 fathoms.

In recent years neither species has been found in water warmer than 1°C. (Fig. 14) The bulk of other information about both species with few exceptions supports the con clusion that both are Arctic forms. Grieg (1921) gives a large number of records fo *Hymenaster*: PORCUPINE, −1·3°C.; VØRINGEN, −1·3° to 1·1°C. (11 records, only one abov zero); MICHAEL SARS, 1900, −1° to 0·11°C.; 1902, −0·32° to 3·36°C.; THOR, −0·58°C. BELGICA, 0·4°C.; the Russian Spitsbergen Expeditions, −1·1° to 0·3°C.; JERMAK, −1·7 to 3·1°C.; VARNA, −1·4° to 1·2°C.; and DIJMPHNA, −1·5° to −0·8°C. Commenting o these temperatures he writes: 'Most of the localities of this species belong to the cold area but it seems to invade the warm area to some extent as the records vary from −1·7°C. t 3·36°C. The warm stations, however, lie close to the limit of the cold area and the hydro graphical conditions may probably therefore vary there.' It would probably be more correc to say that sometimes warm water invades the area where *Hymenaster* lives, which must b cold for the greater part of the time.

Lophaster has a very similar range for all records. The VØRINGEN found it at station with bottom temperatures varying from −1·2°C. to 0·8°C.; MICHAEL SARS from −0·9°C to 3·98°C. The latter temperature relates to a single station on the Faroe-Iceland ridg near the cold and warm-water boundary. Koehler (1924) describes it as an Arctic species but says it has been recorded rarely from water between 6°C. to 7°C. These probably refe to specimens from some of the Norwegian fjords, which Grieg (1921) has distinguished a belonging to a boreal variety of the species. The ERNEST HOLT'S records vary from −0·46°C to 0·96°C. which confirm that, within the Area, *Lophaster* is a pronouncedly Arctic form

Reproduction and development

Hymenaster pellucidus is known to have direct development, and the young are protecte by the female parent (Thorson, 1936). Nothing is known of the development of *Lophaster* but it may, like most other members of the family *Solasteridae*, have large eggs whic develop into lecithotrophic larvae.

8. GORGONOCEPHALUS EUCNEMIS (Müller & Troschel) (=G. MALMGRENI)
G. ARCTICUS Leach (=G. AGASSIZI)
G. LAMARCKI (Müller & Troschel)
G. CAPUT-MEDUSAE (Linnaeus) (=G. LINCKII)

Distribution

G. eucnemis: '. . . widely distributed in the Arctic seas, to Spitsbergen, the Kara Se and the Siberian Sea. It further occurs in the Greenland Seas, down to Cape Cod on the American coast. Its bathymetrical distribution is ca. 15–1850 m.' (Mortensen, 1927).

At Iceland only one specimen has been found – on the east coast (Einarsson, 1948)

G. arcticus: '. . . the Norwegian Sea as far south as 62° 43′N., 1° 26′E., at Spitsbergen in the Barents and Kara Seas and in the Siberian Sea to 164° 28′E. Long. and . . . also found at Jan Mayen and Greenland and at the American coast down to 45°N. Lat. Vertical range about 5–1500 m.' (Einarsson, 1948).

'At Iceland this species is confined to the north and east coasts.'

G. lamarcki: 'In British seas . . . in the warm area of the Faroe Channel. It is otherwise known from Finmark to Bergen, Iceland, Greenland and N. America down to Nova Scotia. Bathymetrical distribution ca. 75–780 m.' (Mortensen, 1927).

At Iceland: 'The species is found in the warm-water area off Iceland and eastwards to the middle of the north coast' (Einarsson, 1948).

G. caput-medusae: '. . . known from Scandinavian and British seas, from Trondheim in the north to Skagerrak, Firth of Forth and S.W. Ireland in the south. Vertical range 150–1200 m.' (Einarsson, 1948).

At Iceland it is found off the south coast.

Previous distribution in the Area (Fig. 15A)

Of the four species of *Gorgonocephalus* known from the North Atlantic, three were reported from the Area. Robertson's records of *G. caput-medusae* must be discounted as they were undoubtedly due to mis-identification of small specimens of *G. eucnemis*. The two other recorded species *G. arcticus* and *G. eucnemis* were both abundant in places. *G. arcticus* was not found as frequently as *G. eucnemis*, being absent from Bear Island and the west of Spitsbergen (apart from findings in the fjords), but it was obtained once on the southern side of Storfjordrenna. Records of *G. eucnemis* are numerous from Bear Island and north and west of Spitsbergen. In the latter area Hartlaub (1900) reports that it occurred in 'colossal masses', but there is no indication that it occurred in such large quantities at Bear Island. There are a few notes of many *G. eucnemis* being caught near Bear Island, usually from the shallower depths, but most of the records from over 100 fathoms are of young specimens.

The Atlantic water species *G. lamarcki* was not found anywhere north of the Finmark coast of Norway.

Present distribution (Fig. 15B)

A number of interesting changes have taken place in the distribution of these species. The most significant is the appearance of *G. lamarcki* amongst the Bear Island fauna for the first time. It has now been found as far as 75° 20′N., which represents a northward spread of over 300 miles. *G. arcticus* has only been found where Arctic conditions persist, on the Great Bank, Storfjord and Storfjord Bank. It has not been found south of Storfjord, or west of Spitsbergen, but it may possibly have been overlooked amongst the large numbers of *G. eucnemis* found on the Hope Island and Central Banks. *G. eucnemis* has been caught in large numbers in the east of the Area, and there it has the same distribution as *Heliometra*. Small specimens of this species still occur around Bear Island, but the large adults (up to 10 cm. diameter of disc) have not been found there in recent years. A most striking change has taken place at Spitsbergen, namely the disappearance of the 'colossal masses' of this species from the fishing grounds south of 78°N., where Atlantic species, such as *Lithodes* and *Hippasteria* have appeared. On the banks north of 79°N. *G. eucnemis* is still abundant, and it has also been found near the entrance of Isfjord. It probably also survives near the entrances to the other west Spitsbergen fjords.

The temperature data below show that *G. lamarcki* is definitely an Atlantic species, while *G. arcticus* is equally definitely an Arctic form. From its general distribution and the fact that it has disappeared from west Spitsbergen along with a number of other Arctic species, *G. eucnemis* must be considered an Arctic species, which perhaps can survive somewhat higher temperatures than the others. The records of this species from north Spitsbergen are of particular interest because they account for many of the anomalous temperature records. As will be discussed later, these may indicate that the changes which have taken place further south may be extending to the northern banks of Spitsbergen.

Temperature and depth ranges

Table A shows at once that depth may be ignored as a factor influencing the distribution of any of these species. All the records for the Area are well within the total known depth ranges of the species.

FIG. 15. *Distributions of* Gorgonocephalus arcticus, G. eucnemis *and* G. lamarcki. *A. Past records. B. Recent records.*

G. lamarcki was not known north of the Finmark coast in the past, but it now occurs beyond 75°N. *G. eucnemis* was abundant off west Spitsbergen in places from which it is now absent, and *Lithodes* and *Hippasteria* are found there instead. *G. arcticus* is now only found where pronounced Arctic conditions prevail. Recent records of *G. eucnemis* from near Bear Island all refer to small specimens, usually found singly, whereas elsewhere large specimens are found in abundance.

The temperature data for each species is much more interesting. The recent records for *G. lamarcki* range from 1·58°C. to 4·03°C. (Fig. 16), but only one is below 2°C. Earlier records confirm that this species is unusual in water below 2°C. Mortensen (1933) gives eight records from the INGOLF expedition, seven of which are between 3·4°C. and 7·8°C. The other, 0·5°C., is from the warm and cold-water boundary on the Faroe-Iceland ridge, which means that it was probably caused by a temporary movement of cold water. The records from the VØRINGEN and the MICHAEL SARS show a similar range, from 3·36°C. to 7·51°C. (This includes two records from the VØRINGEN, which Grieg had earlier attributed to *G. eucnemis*.) Koehler (1924) gives a range of 2°C–7°C. for this species. All these records show that *G. lamarcki* is an Atlantic species.

G. arcticus was only found twice by the INGOLF expedition, in temperatures of 0·2°C. and 1·6°C. Nine records from the VORINGEN and MICHAEL SARS range from −1°C. to 1·1°C., while Koehler (1924) says that it is usually found in temperatures around 0°C. but that it is known from water over 1·5°C. The ERNEST HOLT's records range from −0·47°C. to 1·82°C. (Fig. 16) which agrees with the conclusion that this is an Arctic form.

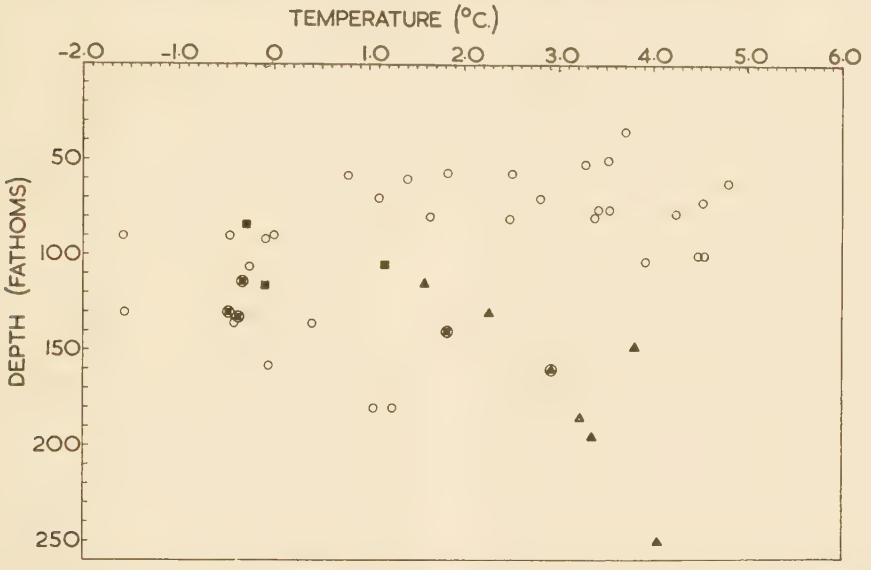


FIG. 16. *Temperature and depth distributions of* Gorgonocephalus arcticus (■), G. eucnemis (○) *and* G. lamarcki (▲).

The temperature data for *G. eucnemis* do not give as clear a picture as that for the other two species. Most of the data support Koehler's description of it as a species from cold water. Of the VØRINGEN's original 17 records, 15 were from temperatures between −1·1°C. and 2·5°C. The two exceptions were from 6·5°C. and 7·0°C., and Grieg later re-examined the specimens and found that they were *G. lamarcki* (Grieg, 1904). The INGOLF expedition only found this species twice, on both occasions in a bottom temperature of 0·2°C. The MICHAEL SARS records range from −0·69°C. to 2·3°C. It is only amongst the recent findings that temperatures much above 2°C. have been found (Fig. 16). The ERNEST HOLT's temperature records for this species range from −1·58°C. to 4·8°C., but the majority are below 2°C. There are two explanations to account for the exceptions. Most of the Bear Island records, especially those west of the island during 1949 and 1950, refer to relatively small specimens which must have developed from larvae carried there by a westerly movement of cold water from the Hope Island Banks. The absence of recent findings of this species west of Bear Island indicates that few of these juveniles can have survived. The other anomalous records are all from the banks near the entrance to Isfjord and further north. It is unlikely that this species or the other Arctic species found at the same stations can survive temperatures of 3°C. or more for very long. This means either that warm water on

these banks is exceptional even in summer, or that the general warming up of the region is continuing, in which case *Gorgonocephalus eucnemis* and the other Arctic species there may be expected to gradually disappear and be replaced by Atlantic species.

Reproduction and development

The development of the three species of *Gorgonocephalus* found in the Area is unknown. The fourth species *G. caput-medusae* is known to shed its eggs freely into the water, and it is probable that the others do the same. Nothing is known about the larvae.

9. Ophiopleura borealis Danielssen & Koren

Distribution

(Mortensen, 1927) 'In British seas . . . found in the cold area of the Faroe Channel 60° 57′N., 4° 38′W., 1098 m. It is a purely Arctic species, characteristic of the cold area of the Norwegian Sea, distributed from East Greenland to Spitsbergen, Franz Joseph Land and the Siberian Sea as far as 124° 41′E.' Bathymetrical distribution, 10–1885 m.

It is not recorded from Iceland by Einarsson (1948).

Past distribution in the Area

There appear to be no previous records of this magnificent ophiuroid from the fishing grounds of the Area. It was found by the VØRINGEN (Grieg, 1893) in deep water west of Spitsbergen and Bear Island (in 459 fathoms and 658 fathoms respectively), and various other expeditions found it in shallow water east of Spitsbergen off Edge Island and North-east Land.

Present distribution (Fig. 7B)

The ERNEST HOLT's findings of this species have all been from the permanent Arctic regions, beyond Hope Island. It has only been found on the northernmost of the Hope Island Banks (nearly 78°N.) and on the Great Bank. There are no records of it even from the Central Bank, although it is a species which might be expected there, and which it is impossible to overlook. It is also absent from the Hope Island Deep where it seems to be replaced by *Ophiura sarsi* which conversely is not found further north. Many other species which are common in the Hope Island Deep such as *Pontaster tenuispinus* and *Ophioscolex glacialis* are equally common further north, which seems to indicate that the restriction of *Ophiopleura borealis* is not due to differences in the nature of the bottom. From the temperature data it seems that *Ophiopleura* is rare even in temperatures near 1°C., which justifies its description as a 'Polar Basin' form. It is probable therefore that in places where this species flourishes, the temperature seldom exceeds zero.

Temperature and depth range

This species has been found in depths ranging from the abyssal (1,030 fathoms) almost to the littoral (3 fathoms), so that it is obvious that depth alone is not important in limiting its distribution.

Recent temperature records (Fig. 12) for this species range from −0·47°C. to +0·42°C. Other data substantially agree with this. The six VØRINGEN findings range from −1·3°C. to −1°C., and the 11 INGOLF records from −1°C. to −0·3°C. Grieg (1910) gives it a total range from −1·79°C. to 1·08°C. The earlier MICHAEL SARS records are from 'the cold area of the Norwegian Sea' (Grieg, 1904) and the later ones range from −1·39°C. to 1·1°C. (Grieg, 1921). As the boundary of Grieg's 'cold area' is the 0°C. isotherm the majority of records of this species are from water with temperatures below 0°C., which shows that it is justifiably called a Polar basin form.

Reproduction and development

Nothing is known about its development other than that it has small eggs (Mortensen, 1933), so it probably has a pelagic ophiopluteus larva like the species of the closely related genera *Ophiura* and *Ophiocten*.

10. Geodia barretti Bowerbank*

Distribution

Spitsbergen, Norwegian coast and southern Barents Sea, Shetlands, Iceland and the Denmark Strait to south and west Greenland.

Past distribution in the Area

There is very little information about the distribution of *Geodia* anywhere, and there are no definite records from the Area. Hartlaub (1900) in his report on the OLGA expedition mentions large sponges at several stations, but there is nothing to indicate that the species was *Geodia*. Appellöf (1912) refers to a catch of over one ton of *Geodia* in a trawl haul

FIG. 17. *Present distribution of* Geodia barretti.

There are no past records of this species north of 72°N. so its occurrence in the Area must be recent. Its presence east of Bear Island indicates a considerable Atlantic influence on the edge of the bank there, probably a very recent happening, since all the specimens are young.

* The author wishes to acknowledge the help of Dr. M. Burton of the British Museum (Natural History) who has kindly identified this and other sponges collected by the ERNEST HOLT.

made by the MICHAEL SARS in the Barents Sea, but no position is given. Robertson at Be Island in 1930 recorded catches of large sponges from somewhere south of Bear Islan but he was unable to bring any specimens back. It is just possible that these were *Geodi* although from the smell which he attributes to them they were perhaps *Axinella arctic*

Burton (1930) gives a table showing the distributions of sponges known from Norwa None of the Norwegian species of the family *Geodiidae* are recorded from Svalbard. It unlikely that such large sponges could be overlooked completely by all the expeditions t the Area, so they must have been absent.

Present distribution (Fig. 17)

These large sponges have been taken very frequently by the ERNEST HOLT. At som stations at the western end of the Bear Island Channel several tons at a time have bee caught in trawl hauls. Further north they are not usually caught in such large quantitie although at Spitsbergen they are very common. The records extending along the edge the banks east of Bear Island towards the Hope Island Deep refer mainly to small spec mens. This species is closely associated with the warm water of the West Spitsberge Current, as the temperature data show. Thus *Geodia* has spread a great distance to th north, following the increased influence of the West Spitsbergen Current, which has als resulted in great northward extension of the ranges of *Lithodes* and other Atlantic specie The small specimens found towards the Hope Island Deep together with occasion findings of *Sabinea sarsi* indicate that there must be some considerable Atlantic influenc there, and if the present warm trend continues *Lithodes* and *Hippasteria* and other Atlanti species may be expected to colonise that area.

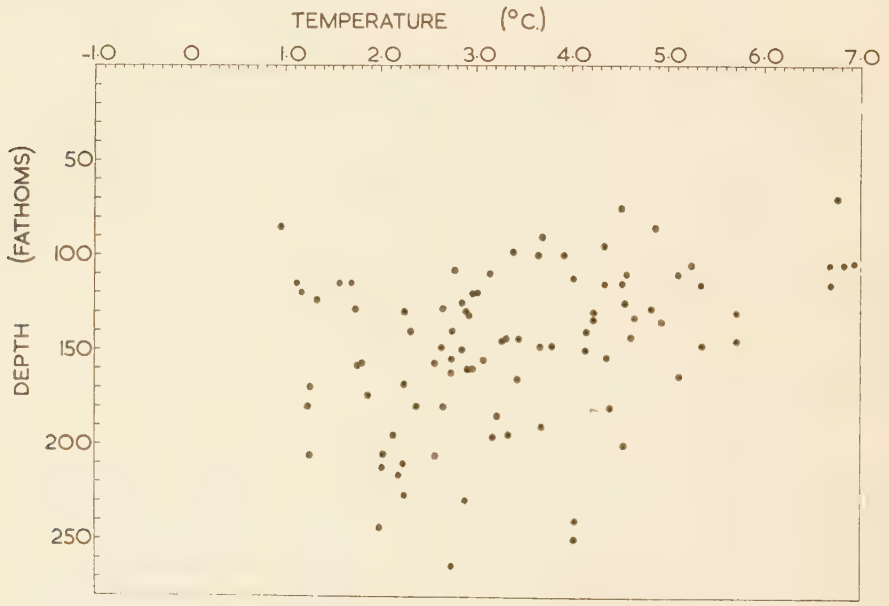


FIG. 18. *Temperature and depth distributions of* Geodia.

Temperature and depth ranges (Fig. 18)

The temperature range for the ERNEST HOLT'S records is from 0·96°C. to 6·94°C., and the depth range 70–265 fathoms. The highest temperatures and the shallowest depths ar for findings outside the Area, on the banks off the north Norway coast. Depth alone is unlikely to affect this species any more than it does the other animals to which reference has been made. Temperature on the other hand is more significant. In water much below 1°C. *Geodia* is absent, and it is rare where temperatures remain below 1·5°C. In fact mos of the records from below that figure are probably caused by local movements of cold water, such as the cascading of cold water off the banks. The absence of records from very

low temperatures shows that this species is restricted to the areas where Atlantic water predominates.

Reproduction and development

The great spread of these species to the north probably indicates that, like many other species of sponge, *Geodia* has a planktonic larva, although there are no observations to prove this. Burton (1949) gives a description of many small specimens of *Geodia* with very large spicules, and puts forward the theory that they arise from the extrusion of regenerative cell masses. This mode of reproduction could partly explain the great quantities of these sponges which occur in some places.

V. THE RELATION BETWEEN BENTHOS AND THE HYDROGRAPHIC CONDITIONS

Our present knowledge of the distribution of various animals in the Area and elsewhere has been summarised in the foregoing paragraphs and charts, together with some data on their temperature and depth ranges. From this information it is possible to pick out two groups of species with restricted ranges. One of these groups, consisting of *Lithodes maia*, *Sabinea sarsi*, *Ceramaster granularis*, *Pseudarchaster parelii*, *Hippasteria phrygiana*, *Gorgonocephalus lamarcki* and *Geodia barretti*, is confined almost exclusively to the western side of the Area, to the banks west of Bear Island and Spitsbergen. Apart from *Geodia*, which is often found in temperatures as low as 1·2°C., the other species of this group are rare in water of less than 2°C. Outside the Area these species are found as far south as the western seaboard of the British Isles, as well as the Norwegian coast, and south and west Iceland. They must all, therefore, be considered as Atlantic species, as they are only found where Atlantic conditions persist.

The other group, consisting of *Sclerocrangon ferox*, *Sabinea septemcarinata*, *Heliometra glacialis*, *Hymenaster pellucidus*, *Lophaster furcifer*, *Gorgonocephalus arcticus*, *G. eucnemis* and *Ophiopleura borealis*, is equally confined to Arctic conditions, namely water with temperatures below 1°C. and a salinity of less than 34·9 ‰.

To be compared with these Arctic and Atlantic species, there are two eurythermal animals *Sclerocrangon boreas* and *Pandalus borealis* which are distributed more or less over the whole Area. The former is if anything limited to depths less than 100 fathoms, while the latter is most abundant in deep water. The main point of interest is that both these species are found over the whole area and over the whole temperature range which occurs there. This contrasts greatly with the restricted distribution of the stenothermal Arctic and Atlantic organisms.

Before going on to draw a picture of the hydrographic conditions near the bottom over the whole Area, it is as well to consider the temperature data in more detail. All the temperature and depth data for recent records of the Arctic and Atlantic species given above are plotted in Fig. 19.

Of the 255 stations shown, Arctic and Atlantic species have only been found together at 10 of them. The two lowest temperatures where species of the opposing groups have been found together, 0·8°C. and 1·24°C., refer to the most easterly records of *Sabinea sarsi* and *Geodia barretti* respectively. These are perhaps the pioneers of a spread of Atlantic species to the east of Bear Island. The other eight occurrences refer to places west of Bear Island where young specimens of *Gorgonocephalus eucnemis* or *Sabinea septemcarinata* have been taken at the edge of the Atlantic zone. Apart from these 10 finds of Arctic and Atlantic species together, there are a number of occasions when either Arctic species have been found in warm water or Atlantic species have been found in cold water. Each of these exceptions has been mentioned in the paragraphs on the various species concerned, so they need only be summarised here. Very low temperatures, around 1°C. or less, where Atlantic species have been found, are considered to be due to cold water cascading through

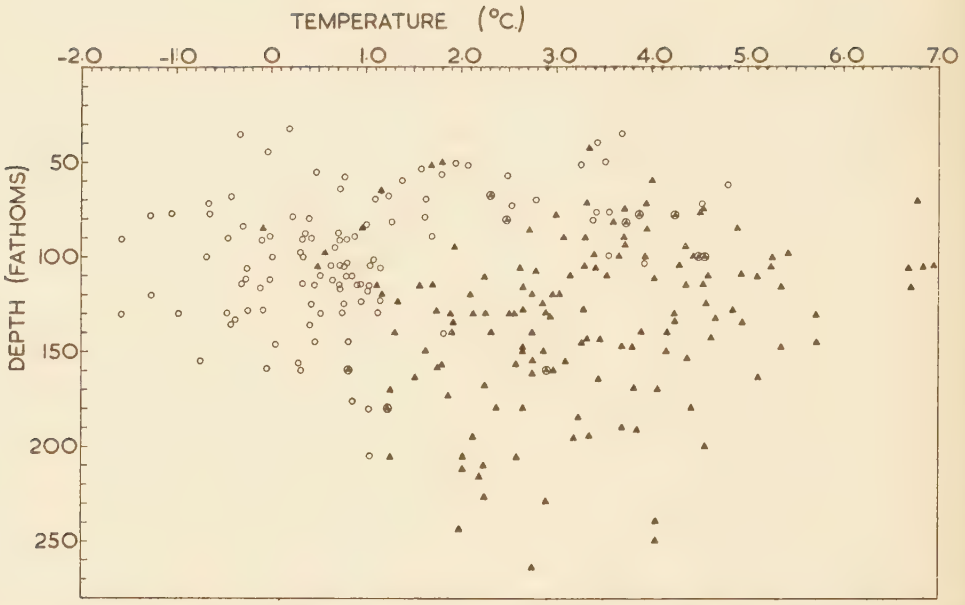


FIG. 19. *Temperature and depth distributions of all Atlantic species* (▲) *and all Arct species* (○).

The Atlantic species are *Lithodes maia, Sabinea sarsi, Hippasteria phrygiana, Gorgonocephalus lamarcki* and *Geodia barretti*. The Arctic species are *Sclerocrangon ferox, Sabinea septemcarinata, Heliometra glacialis, Hymenaster pellucidus, Lophaster furcifer, Gorgonocephalus arcticus, G. eucnemis* and *Ophiopleura borealis*. This confirms that Atlantic species usually occur in water near or more than 2°C., while Arctic species rarely occur in water warmer than 1°C. Reference should be made to Figs. 6 and 11, which show the temperature and depth distributions of two species which are not influenced by these temperature limits.

the Atlantic zone (Lee, 1952). Such cascading water is a transient feature which is unlike to have any lasting effect on Atlantic species living on the bottom. Most of the records Arctic species found in Atlantic conditions are from depths less than 100 fathoms. greater depths there is virtually no overlapping of the temperature range of the finds Arctic and Atlantic forms, which presumably means that hydrographic conditions a more stable in deeper water. Many of the records of Arctic animals in warm water refer juveniles occurring singly, which might not survive and are therefore of little importanc But at seven of these stations in temperatures between 2·8°C. and 4·5°C., typical Arcti communities consisting of large numbers of fully-grown specimens of such species *Heliometra glacialis* and *Gorgonocephalus eucnemis* were found. This means that Arcti conditions with temperatures around 1°C. or less must have predominated in those plac in the recent past. These seven stations were all west of Spitsbergen, two being near th entrance to Isfjord and the others on the banks further north, where Arctic condition would be expected for most of the year. The warm water must have come from an unusuall large influx of Atlantic water into the Area, which resulted in its pushing on to banks t which it does not penetrate normally. This may have been an exceptional happening, bu it might be an indication that the warming-up of the Arctic is still continuing. Animal have recently been found on the edges of some of these northern banks which indicate tha Atlantic conditions predominate there. These warm temperatures on the banks may mea that Atlantic conditions are spreading there in the same way as they have done furthe south. If this happens we expect these Arctic communities to die out and be replaced b Atlantic forms.

Having decided in the first place which are Atlantic and which are Arctic forms, an secondly what significance should be attached to anomalous records of each group c species, it is possible to draw some conclusions about the dominant hydrographic con ditions near the bottom over the whole Area. Fig. 20B gives a chart showing the Atlanti zone based on recent finds of Atlantic species. This shows that the Atlantic water of th

FIG. 20. *Summary charts of the distributions of Atlantic species* (▲) *and Arctic species* (○). *A. All past records. B. All present records.*

The Atlantic species plotted are *Lithodes maia, Sabinea sarsi, Ceramaster granularis, Pseudarchaster parelii, Hippasteria phrygiana, Gorgonocephalus lamarcki* and *Geodia*. The Arctic ones are *Sclerocrangon ferox, Sabinea septemcarinata, Poliometra prolixa, Heliometra glacialis, Hymenaster pellucidus, Lophaster furcifer, G. arcticus, G. eucnemis* and *Ophiopleura borealis*. The stippled area indicates the bottom where Atlantic conditions predominate, as deduced from the occurrence of Atlantic species. Comparison of A and B shows how much the Atlantic influence has increased in recent years. The latest samples show that Atlantic species occur as far as 79° 10′N. west of Spitsbergen. The hatched area covers places where conditions may vary from extreme Atlantic to extreme Arctic conditions (+5°C. to −2°C.). More samples are required from there and from the areas marked ?.

West Spitsbergen Current is the predominant hydrographic factor on the banks along th whole of the west side of the Area as far as 79°N. at least. At Bear Island the Atlantic zon extends from about 80 fathoms downwards. No fishing has been carried out at depth greater than 265 fathoms, so the lower limit of the zone has not been determined, bu according to observations made along the West Bear Island Hydrographic Section, th lower limit of this zone must be at about 330 fathoms (600 m.) (Lee, 1952).

At Spitsbergen, south of Isfjord the Atlantic zone extends into shallower water than Bear Island, namely to about 50 fathoms. Further north, there are not enough records fo the extent of the Atlantic zone to be given in detail, but it seems to be limited to a narro strip at about 100 fathoms depth. Nowhere at Spitsbergen is the lower edge of the zon known. This zone is not necessarily continuous from the southern edge of the Area to i northern limit. A number of finds of large quantities of *Geodia* show that Atlantic condition predominate across the mouth of the Bear Island Channel, but the few temperature record from the entrance to the Storfjordrenna show that Arctic conditions are usually foun there. Likewise there are a few benthos samples from the edge of the channel leading fro Isfjord which show some Arctic influence and indicate perhaps that cold conditions pre dominate in the deeper parts of this channel.

The bank south of the Bear Island Channel is a permanent Atlantic area, as far a 28°E. at least. This region is the northernmost limit of several Atlantic species such a *Munida sarsi* and *Munida tenuimana*, in addition to *Pseudarchaster parelii*, none of whic has been found at Bear Island. This probably indicates that temperatures are uniformly higher there than at Bear Island.

There are no samples from the middle of the Bear Island Channel so that it is impossib to say what conditions prevail there. Along its northern edge, however, some Atlant species occur sparsely at depths around 130 fathoms, as far as 27°E. The small size an numbers of these specimens suggest that this is a recent extension of Atlantic condition

Much of the remainder of the Area is covered by Arctic water. This covers the who of the Hope Island, Central and Great Banks to the east of the Area. The Arctic wate influencing the Hope Island Banks is known as the Bear Island Current. Arctic condition must still predominate on the banks north of Spitsbergen, and probably also in shallo water along the whole west coast of Spitsbergen. Permanent Arctic conditions have bee found in Storfjord and at the eastern end of Storfjordrenna and probably also are to b found in the rest of the Storfjordrenna. Here the East Spitsbergen Current is the Arct influence. East of the Central and Great Banks the few benthos samples that have bee obtained indicate decidedly Arctic conditions, but as there is a possibility that an Atlant water current exists there, much more sampling is needed before that part of the chart ca be filled in.

Finally there are parts of the Area which have not been included in the Atlantic zon nor in the Arctic region. These include the shallow water around Bear Island and th North Bear Island Bank. Although fishing in this shallow water has not been extensive sufficient samples have been obtained to give a good idea of the fauna there. This is o great interest, because species indicative of either Arctic or Atlantic water have nearl always been absent completely, and have never been found in quantity. Their absenc cannot be entirely due to the shallow depths (50 fathoms and less) because, as Table . (p. 33) shows, all except one of the indicator species have been found in depths less tha 50 fathoms, and most of them occur somewhere in depths shallower than 30 fathoms. Th probable explanation of their absence lies in the fact that in this shallow water hydrographi conditions vary more than anywhere else in the Area. Lee (1952) has recorded a temperatur range from −1·8°C. to 5°C. at one place in a depth of 44 fathoms south of Bear Islanc Such a temperature range probably occurs over the whole of this shallow bank, which i ice-covered for many months in winter, and then warms up in summer for a period o several months when warm water from the West Spitsbergen Current moves on to th bank. When cold water cascades through the Atlantic zone it probably traverses that regio quite rapidly and thus has little effect on the Atlantic species living there, but on thi shallow bank, animals are subjected first to extreme cold and then to extreme warmth, eac time for a period of several months. It can therefore be inferred from the absence o

ible A. The depth ranges of selected species within the Area compared with their ranges for their total distribution

Species	*Depth range (fms.) in the area*	*Depth range (fms.) over total distribution*
Heliometra glacialis	52–140	5–740
Ceramaster granularis	–	11–765
Pseudarchaster parelii	–	8–1370
Hippasteria phrygiana	60–206	11–440
Hymenaster pellucidus	84–156	8–1530
Lophaster furcifer	84–136	16–740
Gorgonocephalus arcticus	84–140	3–820
G. eucnemis	35–180	8–1010
G. lamarcki	115–250	41–426
Ophiopleura borealis	84–156	3–1030
Lithodes maia	44–200	35–291
Sclerocrangon boreas	30–160	0–160*
S. ferox	68–176	50–532
Sabinea sarsi	50–173	40–388
S. septemcarinata	33–205	0–205*
Pandalus borealis	50–244	20–495
Geodia barretti	70–265	?

* Greatest depth according to recent findings.

tlantic and Arctic species that neither can withstand such sustained adverse conditions. his shallow water has in fact a rich and characteristic fauna of its own, consisting of such ecies as *Cucumaria frondosa*, *Chlamys islandica*, *Hyas araneus* and various Ascidians such *Halocynthia pyriformis* and *Synoïcium spp.* Polyzoa, including *Lepralia sp.* and a colonial nnelid (*Thelepus cincinnatus*), are also very abundant. In addition the shrimp *Sclerocrangon reas*, which has already been noted as a eurythermal species, is also to be found there. his fauna is also present just south of the entrance to Isfjord, and may be expected in allow water south of there, between Arctic communities near the coast and the Atlantic one in greater depths offshore. It is interesting to note that a very similar fauna occurs in ie southern Barents Sea in the shallow water on the Kanin Bank and near the entrance the White Sea, where summer temperatures are several degrees warmer than at Bear sland.

Before the chart can be completed, various parts of the Area need to be sampled more ully, particularly the northern extremities, the shallow water along the Spitsbergen coast, nd the North Bear Island Bank. Samples are also needed from several places which have ot yet been fished, especially the Bear Island Channel, Storfjordrenna and the wide area outh-west and east of the Central Bank. It would also be of great interest to determine the wer limit of the Atlantic zone along the western slopes of the Area. As fishing is impracti- able in some of these places, either because of rough ground or great depths, underwater hotography may be the only way of obtaining any samples.

Although the coverage of the Area is thus not by any means completed, it is sufficient give a good picture of the distribution of some benthic animals and of the hydrographic onditions which are associated with them. This picture provides a good basis for com- arison with past records to show what changes have taken place in recent times. It can lso provide a basis for the assessment of changes which may take place in the future.

VI. RECENT CHANGES IN THE DISTRIBUTION OF BENTHOS IN THE AREA

The present distributions of certain benthic animals, and the hydrographic condition deduced from these occurrences, have been summarised in Fig. 20B. The findings of these species in the Area before 1931 have already been given for the individual species. All these records have been plotted in Fig. 20A and a general picture of the hydrographic condition on the bottom before 1931 has been drawn from them. This chart shows that there is only a single past record of an Atlantic species north of 75°N. Lat. As this was only a juvenile *Sabinea sarsi*, in a place where even now Atlantic conditions are unlikely to prevail, it can safely be ignored. Thus Atlantic conditions only predominated along the edge of the bank west of Bear Island south of 75°N. and south of the Bear Island Channel. There are no benthos records to show whether or not the Atlantic area at Bear Island was continuous with that south of the Bear Island Channel. What little hydrographic data there is, indicates that the bottom of the Bear Island Channel was covered by cold water (Mohn, 1883, and Helland-Hansen and Nansen, 1909). The area of maximum variation, based on the same eurythermal species as those used for deducing that area in Fig. 20B, was restricted to a small area west and north of Bear Island. Arctic conditions must have predominated near the bottom, over the whole of the remainder of the Area.

Comparison of Figs. 20A and 20B shows at once what changes have taken place in the Area in recent years. The zone where Atlantic conditions prevail has extended from 75°N. to at least 79°N. It covers most of the fishing grounds off the west of Spitsbergen as far as 78°N., and from there continues northwards as a narrow band along the 100-fathom contour. In addition Atlantic conditions have affected places east of Bear Island, and there are indications that they may be spreading along the southern edge of Storfjordrenna. The zone is now definitely continuous across the western end of the Bear Island Channel and is known to extend further east, over the banks south of this channel, but how much further is not yet determined. This great spread of Atlantic conditions is represented by the appearance of *Lithodes*, *Hippasteria*, *Geodia* and adult *Sabinea sarsi* at Spitsbergen for the first time; by the first finds of *Ceramaster granularis* north of the Bear Island Channel and of *Gorgonocephalus lamarcki* north of the Finmark coast of Norway. In addition Atlantic species are much more frequent at Bear Island than they used to be.

With this extension of the Atlantic zone there has been a complementary decline in some of the areas where formerly Arctic conditions predominated. West of Spitsbergen where Arctic communities used to flourish, they are now absent except from the more northerly banks and in inshore waters. Likewise some of the Arctic species such as *Heliometra* and *Poliometra*, which had been found at Bear Island in the past, even though they may not have been abundant there, are now completely absent. Arctic conditions still prevail in Storfjord and on the Hope Island, Central and Great Banks, but not on the North Bear Island Bank. This bank is now part of the region where conditions vary to their maximum extent so that neither Atlantic nor Arctic conditions predominate there, but they cover the area in turn for periods of several months each year. The area affected thus seems to be about four times as great now as it was in the past.

Although the deduction of this climatic change is based on the detailed distribution of only a small number of species, it is not intended to convey the idea that these species are the only ones which show such changes. Those dealt with in detail were chosen because they are conspicuous and hence there are more records of them than of smaller and less obvious species. Several of the latter show the same northwards spread as *Ceramaster* and *Gorgonocephalus lamarcki* in that they have only recently appeared at Bear Island but were known from many places further south in the past. These include *Leptoptychaster arcticus* and *Ophioscolex purpureus*. Another very interesting find probably linked with this spread of Atlantic conditions is a single specimen of an Asteroid *Tremaster mirabilis* which has only once before been found in Europe. Elsewhere this species is only known from off

Nova Scotia where the type-specimen was found. To be compared with these newcomers to the Area there are several, besides *Poliometra prolixa*, which were well known there in the past, but which have not been taken in recent years by the ERNEST HOLT. These species include the echinoderms *Solaster squamatus* and *S. glacialis*, *Stegophiura nodosa* and *Pourtalesia jeffreysi*.

When exactly these changes began, it is impossible to ascertain. As late as 1930 *Heliometra*, one of the Arctic species which has since disappeared, was still present at Bear Island, but this does not necessarily mean that changes had not begun before then. The fact that the cod had reappeared as early as 1923 off Spitsbergen indicates that changes in the hydrography of the region must have begun in that year at the latest. At that time they may not have affected the benthos to any great extent. Later on, when conditions became more or less permanently adverse to Arctic species, the advent of the trawl fishery around Bear Island may have hastened the extinction of such fragile species as *Heliometra* and *Poliometra*. However, for a number of reasons the trawl cannot be considered as a major factor in producing the changes which have taken place. Intensive trawling may possibly produce some changes in the bottom fauna (Graham, 1956), but where the greatest changes have taken place, namely off Spitsbergen, trawling is rarely carried out intensively, and some of the banks are never trawled commercially. Furthermore, even if trawling alone could account for the disappearance of some animals, it can hardly explain the fact that all these should be Arctic species, while all the species that have replaced them are associated with Atlantic water.

VII. THE MECHANISM PRODUCING THE CHANGES

The hydrographic conditions in the western half of the Area are a balance between the warm West Spitsbergen Current and two cold currents, the Bear Island Current and the East Spitsbergen Current (Fig. 21). Fig. 20A shows that before about 1930 the Arctic currents were dominant on the bottom, and that the West Spitsbergen Current did not influence the bottom greatly, beyond 75°N. The hydrographic sections of Mohn (1883) show that only a small part of the bottom off West Spitsbergen was covered by water over 2°C. even in the months of August and September, and the few later observations confirm this. Under these conditions the Arctic community was continuous from the permanent Arctic waters of Storfjord and further east, along the whole west coast of Spitsbergen to the northern banks where it joined with the Polar basin Arctic community. Because it was continuous in this way, the Arctic community west of Spitsbergen was able to flourish in spite of the fact that the water covering it was always moving northwards. Larvae to maintain the population were brought from the communities further upstream, and this applied all along the west coast of Spitsbergen.

Consider now, what would happen if this north-going part of the East Spitsbergen Current were replaced by one still travelling in the same direction, but coming from a place where no Arctic community flourished. Now the southernmost Arctic community would be cut off from its source of recruits east of Spitsbergen, but its own eggs and larvae would still be carried northwards to maintain populations there. Deprived of recruits this community must eventually die out and the process would continue further north. Thus all the Arctic communities covered by this new current would gradually die out and would be replaced by different species whose larvae were introduced by the new current.

This in fact is what must have happened at Spitsbergen. The East Spitsbergen Current has been reduced so that it is no longer the predominant influence along the west coast of Spitsbergen, except perhaps close inshore. Correspondingly the West Spitsbergen Current has greatly increased in volume so that it now covers most of the banks as far north as Isfjord, and has a marked influence even further north. A similar chain of events must have caused the disappearance of most Arctic species from the Bear Island region. There is no

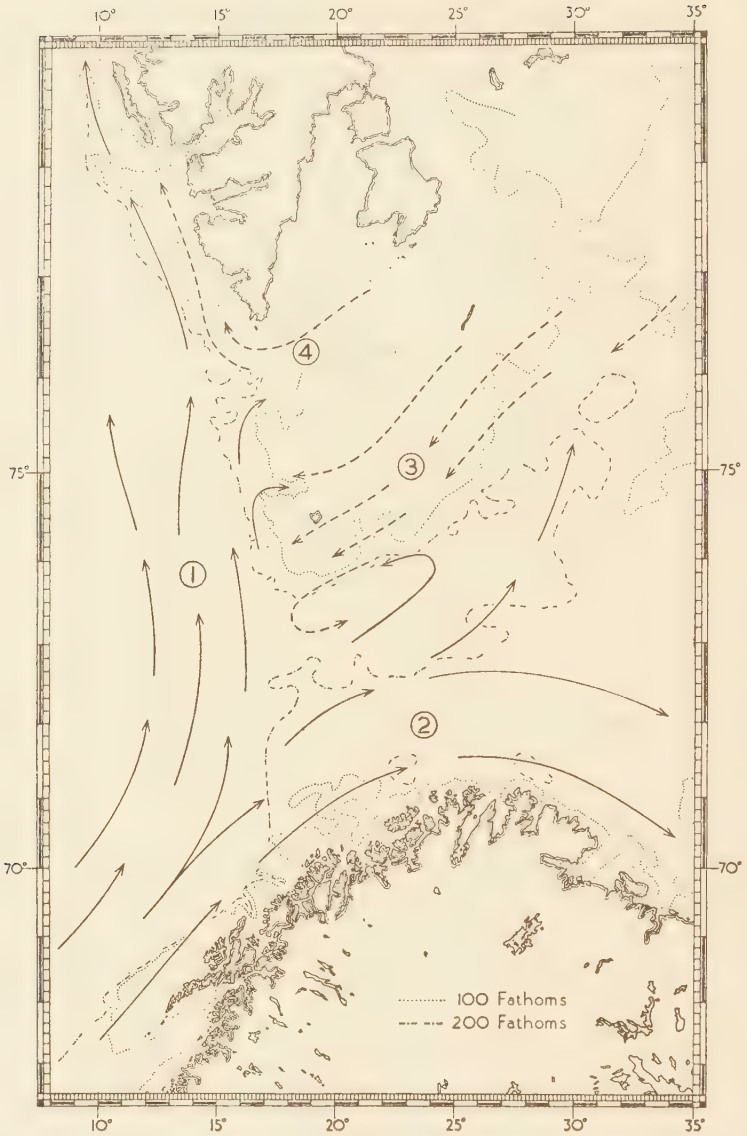


FIG. 21. *General current system of the western Barents Sea, showing the two Atlantic water currents, the West Spitsbergen Current* (1), *the North Cape Current* (2); *and the two Arctic water currents, the Bear Island Current* (3), *the East Spitsbergen Current* (4). (After Lee, 1952).

evidence to show that the Arctic community around Bear Island ever flourished sufficiently to provide a source of larvae to such distant places as Spitsbergen. Bear Island seems to have marked the south-western fringe of the Arctic part of the Area. The Atlantic influence of the West Spitsbergen Current always seems to have been marked there, but even today the Bear Island Current seems to occasionally assert itself and deposits some larvae of rather more tolerant Arctic species such as *Gorgonocephalus eucnemis* and *Sabinea septemcarinata* west of Bear Island.

The changes which have taken place amongst the benthos of the Area, may thus be explained purely mechanically as the result of this change of currents. In fact, besides having different sources, the two currents concerned have markedly different physical and chemical characteristics. The West Spitsbergen Current consisting of water over 2·5°C. and salinity greater than 35‰, while the East Spitsbergen Current has temperatures

round 1°C. or less, and a salinity of less than 34·9‰. These differences cannot fail to accelerate the mechanical changes. Nothing is known about what happens when Arctic animals are subjected to high temperatures and salinities for long periods, but when the converse happens and warm-water species are subjected to very cold conditions, one of the effects is the killing of eggs and larvae, although the adults may survive very adverse conditions. This is supported by some observations off Den Helder, Holland, during the cold winter of 1947, where such crustacea as *Cancer pagurus*, *Portunus holsatus*, *Carcinus maenas* and *Crangon crangon* survived the heavy icing of that winter, but the eggs attached to their pleopods were killed (Thorson, 1950). Presumably a long-term change from Arctic to Atlantic conditions would have a similar effect on Arctic species, and would hasten their disappearance.

This explanation of the changes in the distribution of benthos is based partly on an assumption that most of the species concerned have pelagic larvae. Little is known about the reproduction and development of the animals concerned. Four of the six Decapod Crustacea, *Lithodes maia*, *Sabinea sarsi*, *S. septemcarinata* and *Pandalus borealis* are known to have planktonic larval stages, whilst the larvae of both species of *Sclerocrangon* metamorphose before the eggs hatch, and the juveniles are unlikely ever to leave the bottom. Of the echinoderms, *Hymenaster pellucidus* is the only species whose reproduction is known, and it broods its young. From the knowledge of closely related species it can safely be inferred that *Heliometra glacialis*, the three species of *Gorgonocephalus* and *Ophiopleura borealis* all have planktonic larvae. Of the remaining species, nothing at all is known about the reproduction of *Lophaster furcifer* and *Pseudarchaster parelii*. The other two Asteroids, *Ceramaster granularis* and *Hippasteria phrygiana*, produce large yolky eggs which probably hatch into lecithotrophic pelagic larvae. The remaining species, the sponge *Geodia barretti*, probably has pelagic larvae like so many other sponges, in addition to its possible reproduction by means of regenerative cell masses. Thus of 17 species concerned only three are known which definitely do not have pelagic larvae. Of these one is a eurythermal species whose distribution has remained unchanged, while the other two have only been found in purely Arctic conditions, which suggests that they are especially sensitive to changes of physical and chemical conditions. Of the other species four are known to have, and eight of the other almost certainly do have, planktonic larvae. Thus of the Atlantic forms, all of them except perhaps *Pseudarchaster* may have pelagic stages, and the fact that, with the same exception, they have spread so rapidly seems to confirm this. Perhaps *Pseudarchaster* has not spread in the same way because it has no pelagic stage. With two, maybe three, exceptions all the Arctic species seem to have planktonic larvae.

The assumption that most of the species have pelagic larvae therefore seems on the whole to be justified. Planktonic larval stages strictly are only needed to account for the arrival of the Atlantic species in the Area, and their rapid spread northwards. Without planktonic stages the spread of these species would have been very slow, and it is doubtful if any species with non-pelagic eggs or development will be found closely associated with Atlantic conditions, north of Bear Island. The disappearance from west of Spitsbergen of those Arctic species with planktonic larvae could have been entirely due to the mechanical effect of the alteration of currents, but the physical and chemical changes brought about by the changes of currents may have played as great a part in the extinction of these forms as they did amongst species with non-pelagic development.

VIII. CONCLUSION

It has been shown that the distributions of some of the benthic animals of the Svalbard region are so closely linked with hydrographic conditions that it is possible to deduce from differences in their distributions over a period of years, what hydrographic changes have taken place. Changes in the distribution of benthos in the Area since about 1930 indicate that there has been a great increase in the area of bottom over which Atlantic conditions are predominant, and a corresponding decline in the area influenced by Arctic conditions.

Apart from their effect on the benthos these hydrographic changes have resulted in change of the fish fauna, the most important of these being the great increase in numbers of co which has led to the establishment of the Bear Island cod fishery (Lee, 1949). As a reversio to pronounced Arctic conditions at Bear Island would undoubtedly have a great effect o this fishery, it is important that anything which might give evidence that the warming of th region is continuing or that cooling has started, should be examined.

How far the study of the benthos can help is problematical, but it may be of us because benthos organisms are indicators of the dominant conditions over a long perio The hydrographic factors normally measured, surface and bottom temperatures, salinit and so on, can vary so rapidly that isolated observations can be misleading, but the bentho which is unable to avoid these sudden changes can, as has been shown, indicate whethe or not a bottom temperature observation is exceptional. At the present time the source most of the bottom temperature anomalies which are significant is the area north of Spits bergen, where the first signs of cooling of the region may be expected. The present an malies, however, are all of Arctic species in exceptionally warm temperatures. Admitted all these observations have been made in August and September when sea temperatur are near their maximum, but elsewhere the same species at the same time of year have alway been found in temperatures around 1°C. or less. These exceptionally high temperatur may therefore mean that the region is still warming up. Bottom temperatures and bentho samples are unfortunately not available from north of Spitsbergen at other times of th year, when the finding of high temperatures there would be more significant of continu warming. Additional evidence of continued warming of the sea in that area exists in th fact that several times in recent years the harbour of the mining and tourist centre Ny-Ålesund in Kongsfjorden has remained ice-free even in winter (Heintz, 1950).

Nearly all the anomalous records of Atlantic species are from the winter and sprin months when Arctic water normally reaches its southern and western extremes, and wh cascading of cold water through the Atlantic zone is most likely to take place. These fe exceptions cannot therefore be interpreted as the beginnings of a long-term cooling. Th would most likely be indicated by the repeated finding of Atlantic species in Arctic wat during summer and autumn when sea temperatures should be at their highest.

Eventually, if warming-up continues long enough, the Arctic communities on the ban north of Spitsbergen will die out and be replaced by Atlantic species. When the cooling down starts, Arctic species will re-establish themselves and the northern limit of Atlanti species will retreat southwards. It is not known how long changes in conditions must la before they begin to affect the benthos. Much must depend on how the changes take plac If the change from Arctic to Atlantic conditions is sudden and permanent, then the effe must become noticeable sooner than it would if the change began as a period of alternati of Arctic and Atlantic conditions. In the latter case there may be a period when bo Arctic and Atlantic species are absent and a fauna characteristic of such variable conditio may develop similar to that found on the North Bear Island bank. Thus whatever happe to the hydrographic conditions any long-term changes will be reflected sooner or later the bottom fauna.

The benthos will not give an immediate answer to the question of whether the warming up of the Arctic seas is still continuing, or whether the reverse process has started. Bu neither will any other observations unless they are continuous throughout the year and ar made every year. Although our present knowledge of the benthos of the Area is not a detailed as is desirable, it does, however, provide a basis for future comparisons. A sma number of benthos samples a few years or decades hence will show whether or not the faun has changed and if it has, it will indicate whether warming or cooling has taken plac

IX. SUMMARY

The area covered by the ERNEST HOLT's investigations and the methods used for the collection of benthos are described. Certain species were selected because they were caught frequently enough for their full range of distribution to be worked out.

A brief account is given of the past work in the Area between the years 1878 and 1931, carried out by oceanographic cruises as well as some expeditions to investigate the fisheries of the Area.

Detailed charts of the distributions of the selected species from past and present records are given, together with information about the temperature and depth ranges and the method of reproduction of each species.

It is shown from the present-day findings that some of the selected species are characteristic of Arctic conditions and others of Atlantic conditions. For comparison two eurythermal species which are widespread over the whole Area are included.

The differences between the past and present distributions of the indicator species have been used to show how hydrographic conditions have changed in recent years.

These differences have been explained as the result of a greatly increased average influx of Atlantic water into the Area which has led to the decline of Arctic species off west Spitsbergen and at Bear Island and to their replacement by Atlantic species. The way in which these changes may have been brought about is discussed.

The possibility of benthos indicator species giving evidence of whether or not the Arctic regions are continuing to warm up is discussed.

X. REFERENCES

THLMANN, H. W., 1949. Climatic changes in the Arctic in relation to Plants and Animals. Introductory Address. *Cons. Perm. Internat. Explor. Mer, Rapp. et Proc.-Verb.*, **125,** 9-16. Copenhagen.

APPELLÖF, A., 1912. Invertebrate bottom fauna of the Norwegian Sea and North Atlantic. *The Depths of the Ocean* (Murray and Hjort), pp. 457-560. London.

BIRULA, A., 1907. Zoologische Ergebnisse der Russischen Expeditionen nach Spitzbergen. Crustacea Decapoda. *Ann. Mus. Zool. Acad. Imp. Sci.* St. Petersbourg, **Tome XI,** 1906, 1-68.

BURTON, M., 1930. Norwegian Sponges from the Norman Collection. *Proc. Zool. Soc. London*, 1930, 487-546.

——, 1949. Non-sexual reproduction in sponges, with special reference to a collection of young *Geodia. Proc. Linn. Soc. London*, **160,** 1947–48, Pt. 2, 163–78.

CLARK, A. H., 1923. Crinoida. *Danish Ingolf-Exped.*, **IV.** (5). Copenhagen.

DANIELSSEN, D. C., 1892. Zoology. Crinoida. *The Norwegian North Atlantic Expedition*, 1876–1878. Christiania.

DANIELSSEN, D. C., AND KOREN, J., 1884. Zoology. Asteroidea. *The Norwegian North Atlantic Expedition*, 1876–1878. Christiania.

DÖDERLEIN, L., 1900. Zoologische Ergebnisse einer Untersuchungsfahrt des deutschen Seefischerei-Vereins nach der Bäreninsel und Westspitzbergen. II. Die Echinodermen. *Wiss. Meeresunters.*, N.F. **4,** 195–248, 1900. Kiel & Leipzig.

EINARSSON, H., 1948. Echinoderma. *Zool. of Iceland*, **IV,** part 70. Copenhagen & Reykjavik.

FRIDRIKSSON, A., 1949. Boreo-tended changes in the Marine Vertebrate Fauna of Iceland during the last twenty-five years. *Cons. Perm. Internat. Explor. Mer, Rapp. et Proc.-Verb.*, **125,** 30–32. Copenhagen.

GRAHAM, M., 1955. Effect of trawling on animals of the sea bed. *Papers in Marine Biology and Oceanography, Deep-sea Res. Suppl.*, **Vol. 3,** 1–6. London and New York.

GRAHAM, M., *et al.*, 1954. Report on Research from the *Ernest Holt* into the Fishery near Bear Island 1949 and 1950. *Fish. Invest.*, Series II, **XVIII,** (3). London.

Grieg, J. A., 1893. Zoology. Ophiuroidea. *Norwegian North Atlantic Expedition*, 1876–7 Christiania.
——, 1904. Echinodermen von dem Norwegischen Fischereidampfer 'Michael Sars' in den Jahr 1900–1903 gesammelt. I. Ophiuroidea. *Bergens mus. Aarbog* 1903, (13). Bergen.
——, 1905. Echinodermen von dem Norwegischen Fischereidampfer 'Michael Sars' in den Jahr 1900–1903 gesammelt. II. Crinoidea. *Bergens mus. Aarbog* 1904, (5). Bergen.
——, 1907a. Echinodermen von dem Norwegischen Fischereidampfer 'Michael Sars' in d Jahren 1900–1903 gesammelt. III. Asteroidea. *Bergens mus. Aarbog* 1906, (13). Bergen.
——, 1907b. Invertébrés du fond. *Duc d'Orléans, Croisière océanographique dans la mer du Grönla en* 1905, pp. 503–68. Brussels.
——, 1910. Échinodermes. *Duc d'Orléans, Campagne Arctique de* 1907. Brussels.
——, 1921. Echinodermata. *Rep. Sci. Res. 'Michael Sars' North Atlantic Deep-Sea Exped.* 191 **III,** Part II. Bergen.
——, 1925. Evertebrater fra bankerne ved Spitsbergen. *Bergens mus. Aarbok*, 1923–24 (9). Berge
——, 1927a. Evertebrater fra bankerne ved Spitsbergen. *Bergens mus. Aarbok*, 1926, (5). Berge
——, 1927b. Decapoda Crustacea from the West Coast of Norway and the North Atlant *Bergens mus. Aarbok*, 1926, (7). Bergen.
——, 1931. Echinoderma fra bankene ved Bjørnøya. *Bergens mus. Aarbok*, 1931, (3). Bergen.
——, 1933. Decapoda Crustacea fra bankene ved Svalbard. *Bergens mus. Aarbok*, 1932, (Bergen.
Hansen, H. J., 1908. Crustacea Malacostraca. I. *Danish Ingolf-Exped.* **III,** 2.
Hansen, P. M., 1949. Studies on the biology of the Cod in Greenland Waters. *Cons. Per Internat. Explor. Mer, Rapp. et Proc.-Verb.*, **123.** Copenhagen.
Hartlaub, C., 1900. Zoologische Ergebnisse einer Untersuchungsfahrt des deutschen Se fischerei-Vereins nach der Bäreninsel und Westspitzbergen ausgeführt in Sommer 1898 a S.M.S. 'Olga'. Einleitung. *Wiss. Meeresunters.* N.S. **IV,** Abt. Helgoland, 171–194. Kiel a Leipzig.
Helland-Hansen, B., and Nansen, F., 1909. The Norwegian Sea. *Rep. Norwegian Fi Mar. Invest.* **II,** 1909, (2). Kristiania.
Heintz, A., and others, 1950. Svalbard, A Norwegian Outpost. Bergen.
Hofsten, Nils V., 1916. Die Decapoden Crustaceen des Eisfjords. *Kungl. Svenska Vet. Ak Handl.* **54,** (7).
Hoel, A., 1953. Flateinnholdet av Breer og Snøfonner i Norge. *Norsk Geogr. Tidsskr.* XI 109–123.
Jensen, Ad. S., 1939. Concerning a change of climate during recent decades in the Arctic a Subarctic regions. *Kgl. Danske Vid. Selsk., Biol. Medd.* **14.** Copenhagen.
Koehler, R., 1909. Échinodermes provenant des campagnes du yacht 'Princesse-Ali (Astéries, Ophiures, Échinides et Crinoïdes). *Résultats Camp. Sci.* Fasc. **XXXIV.** Mona
——, 1924. Les Échinodermes des Mers d'Europe I (Astéridés et Ophiuridés). Paris.
——, 1927. **II** (Échinidés, Crinoidés et Holothuridés). Paris.
Lee, A. J., 1949. The Forecasting of Climatic Fluctuations and its Importance to the Arc Fishery. *Cons. Perm. Internat. Explor. Mer, Rapp. et Proc.-Verb.*, **125,** 40–41. Copenhag
——, 1952. The Influence of Hydrography on the Bear Island Cod Fishery. *Cons. Perm. Intern Explor. Mer, Rapp. et Proc.-Verb.*, **131,** 74–102. Copenhagen.
Mohn, H., 1883. Meteorology. *The Norwegian North-Atlantic Exped.* 1876–78. Christiania.
Mortensen, Th., 1910. Report on the Echinoderms collected by the Danmark Expedition North-East Greenland. *Medd. om Grønland*, **XLV,** (4). Copenhagen.
——, 1927. Handbook of the Echinoderms of the British Isles. London.
——, 1933. Ophiuroidea. *Danish Ingolf-Exped.*, **IV,** (8). Copenhagen.
Mosby, H., 1938. Svalbard Waters. *Geofysiske Pub.*, **XII,** (4). Oslo.
Nansen, F., 1902. Oceanography of the North Polar Basin. *The Norwegian North Polar Expe tion* 1893–1896, *Sci. Results*, **III,** (9). Christiana.
Rathbun, M. J., 1929. Canadian Atlantic Fauna. 10. Arthropoda 10 m. Decapoda. St. Andrew N.B.
Robertson, J. A., 1932. A cursory survey of the Bear Island trawling ground. *Cons. Per Internat. Explor. Mer, Rapp. et Proc.-Verb.*, **81,** 115–139. Copenhagen.
Sars, G. O., 1885–86. Zoology. Crustacea I and II. *The Norwegian North Atlantic Expe* 1876–78. Christiania.
Schokalsky, J., 1936. Recent Russian Researches in the Arctic Sea and in the Mountains Central Asia. *Scot. Geogr. Mag.* **52,** (2) 73–84. Edinburgh.

MED, J., 1949. The increase in the sea temperature in Northern waters during recent years. *Cons. Perm. Internat. Explor. Mer, Rapp. et Proc.-Verb.*, **125,** 21–25. Copenhagen.

EPHENSEN, K., 1939. Crustacea Decapoda. *Zoology of Iceland*, **III,** (25). Copenhagen and Reykjavik.

ANASIJCUK, N., 1929. Beiträge zur Kenntnis der Fauna des Barents-Meeres. 1. Über den Einfluss des Nordkapstromes auf die Fauna des Kola-Fjords. *Trav. Stat. Biol. Murman*, **III,** 1–31. Murmansk.

ÅNING, A. V., 1949. On changes in the marine fauna of the North-Western Atlantic area, with special reference to Greenland. *Cons. Perm. Internat. Explor. Mer, Rapp. et Proc.-Verb.*, **125,** 27–29. Copenhagen.

HORSON, G., 1936. The larval development, growth and metabolism of Arctic marine bottom invertebrates, compared with those of other seas. *Medd. om Grønland*, **100,** (6). Copenhagen.

—, 1950. Reproductive and larval ecology of marine bottom invertebrates. *Biol. Rev.*, **25,** 1–45. Cambridge.

ILLETT, H. C., 1950. Temperature trends of the past century. *Roy. Meteorol. Soc., Cent. Proc.*, 195–211. London.

APPENDIX 1

SOME NOTES ON THE IDENTIFICATION OF THE VARIOUS INDICATOR SPECIES

The following notes and diagrams are primarily intended to help in the identification indicator species amongst the benthos of the Barents Sea. Elsewhere they should be us with caution. Off the Norwegian coast and at Greenland and Iceland larger numbers species are found and the characteristics described below may not be sufficient in sor cases for separation of the species in those regions. In such places, reference should made to the accepted systematic works for confirmation of identification.

Most of the diagrams have been especially drawn by the author from specime collected by the ERNEST HOLT.

1. *Lithodes maia* (L.) (Fig. 22)

There is no other species found on the Arctic fishing-grounds which can be confus with this crab. Its carapace is armed with strong spines, particularly around its margi and its legs are also spiny. The long rostrum with a bifid tip distinguishes it from most the nearly related species, all of which are abyssal forms, never likely to be found on t fishing-grounds. The sexes are distinguished by the abdominal plates, which are arrang

FIG. 22. *Lithodes maia* (Redrawn from a figure in Rathbun, 1929).

symmetrically in the male and asymmetrically in the female. It grows to a large size, up six inches across the carapace, with a leg span of two feet or more. Colour in life a da red-brown.

More information about its breeding habits is required, particularly about the breedi season, and whether it ever attains sexual maturity at the northern limits of its range.

2. *Sabinea sarsi* Smith *and S. septemcarinata* (Sabine) (Fig. 23a-e)

The genus *Sabinea* is distinguished from others of the *Crangonidae* by the presen of seven rows of spines along the carapace – a median row of five or six spines of vario sizes, with three rows on each side. The two species are distinguished by the differe shapes of the rostrum and telson. In *S. sarsi* (Fig. 23a) the rostrum projects beyond t eyes and is pointed (Fig. 23b) and the telson is sharply pointed with one or two sm spines on each side of the point (Fig. 23c). In *S. septemcarinata* the rostrum barely reach beyond the eyes and is rounded (Fig. 23d) while the telson is also rounded with a frin of small spines across the end (Fig. 23e).

Both species attain a maximum size of 7 to 8 cm. and in life their colour is light brow mottled with dark brown, and sometimes ivory and green.

3. *Sclerocrangon boreas* (Phipps) *and S. ferox* (Owen)

The genus is characterised by its heavy build with the carapace armed with a medi row of spines and a lateral row of spines or tubercles. The first five segments of t

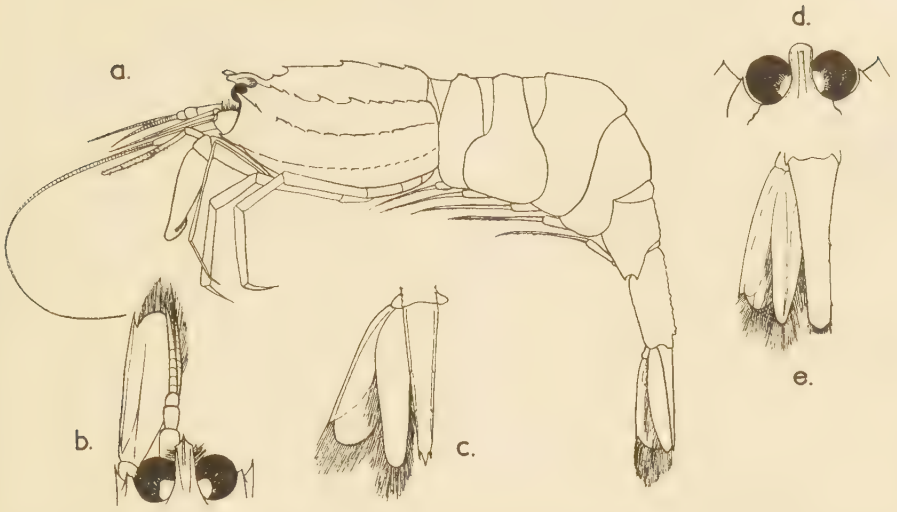


FIG. 23

(a-c) *Sabinea sarsi*, (a) lateral view (about threequarters natural size), (b) rostrum, (c) telson, (d, e) *Sabinea septemcarinata*, (d) rostrum, (e) telson.

bdomen have a more or less prominent median ridge and the sixth has two longitudinal idges. The two species are separated as follows:

S. boreas (Fig. 24): rostrum horizontal or down-turned, bluntly pointed; lateral ridges of carapace tubercular; median ridge of abdomen not very prominent; margins of the first and second epimeral plates of the abdomen smooth; telson broad and bluntly pointed.

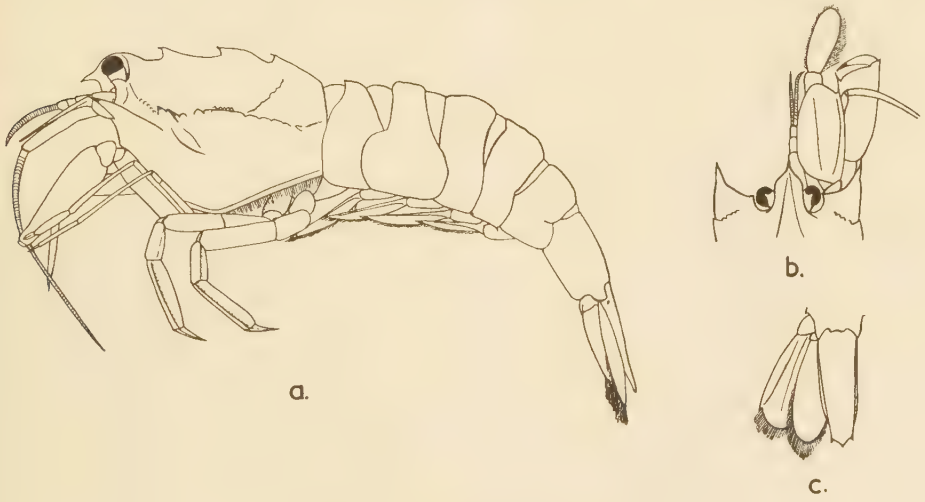


FIG. 24. *Sclerocrangon boreas.*

(a) lateral view (half natural size), (b) rostrum, (c) telson.

S. ferox (Fig. 25): rostrum sharply pointed, the point directed upwards; median ridge of carapace with two large spines and a smaller one; lateral ridge armed with two or more spines; median ridge of abdominal segments very marked; margins of all the epimeral plates armed with stout spines; telson narrow and sharply pointed.

Both species grow to a large size, up to 12 or 13 cm. Colour in life reddish-brown, often mottled with ivory, especially in small specimens of *S. boreas*.

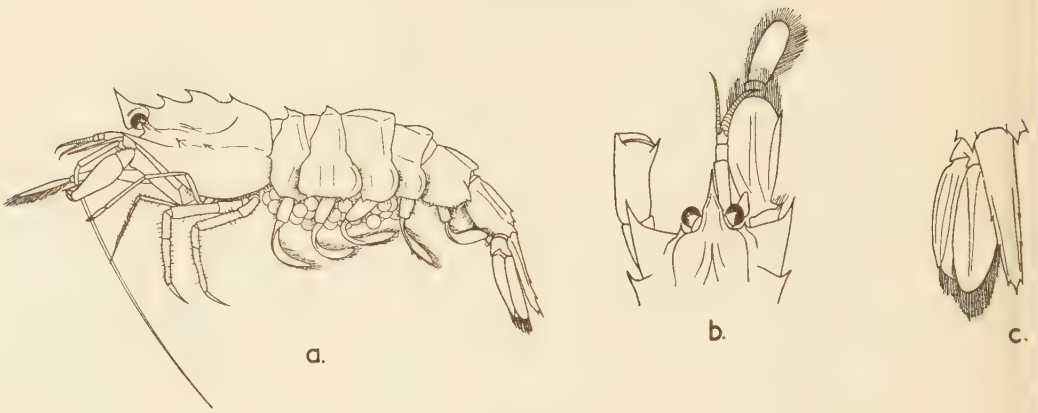


FIG. 25. *Sclerocrangon ferox.*
(a) lateral view (about half natural size), (b) rostrum, (c) telson.

FIG. 26
(a) *Heliometra glacialis* (about natural size).
(b) *Poliometra prolixa*, cirrus from a small specimen ($\times 1\frac{1}{2}$), note the long slender joints compared with the short stout ones of *Heliometra*.

Heliometra glacialis (Leach) (Fig. 26a)

Readers are referred to the keys given by Clark (1923) and Mortensen (1927) for the identification of crinoids of the North Atlantic. In the Svalbard region only *Heliometra* and *Poliometra* are likely to be found in normal fishing depths, but at Iceland and Greenland several other species occur owing to the wider range of hydrographic conditions there.

Adult *Heliometra* are easily distinguished from *Poliometra* by their large size (up to 30 cm. length of arm) and their robust build. *Poliometra* is much smaller and more slender. Juveniles of both species are more difficult to separate, the main distinguishing feature being the length of the cirri, which are short in *Heliometra* and long and slender in *Poliometra* (Fig. 26b). Colour in life: *Heliometra:* arms and cirri yellowish with brown disk; *Poliometra:* arms brownish-yellow and cirri white, disk light brown.

4. *Ceramaster granularis* (Müller), *Hippasteria phrygiana* (Parelius) *and Pseudarchaster parelii* (Düben and Koren)

Ceramaster granularis (Fig. 27a, b) is easily recognised by its flat pentagonal shape (Fig. 27a) with the arms very short. All the plates are covered with small granules, which on the dorsal surface are grouped into a pattern of irregular hexagons. The marginal plates (Fig. 27b) are very distinct, the upper ones always have a patch bare of granules and the lower ones usually do also, especially the ones along the arms. Reaches a size of about 100 mm. diameter, and in life is bright red in colour on the upper surface, paler underneath.

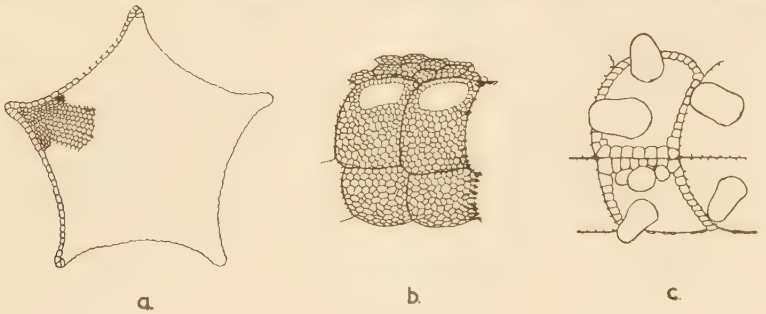


FIG. 27

(a, b) *Ceramaster granularis*. (a) dorsal view (one-third natural size), (b) marginal plates, (c) marginal plates of *Hippasteria phrygiana*.

Hippasteria phrygiana has the same pentagonal outline as *Ceramaster*, but the upper surface is more arched and the arms may be longer. The species is easily distinguished by the dorsal and marginal plates. Most of the former are more or less circular with a series of grains around the edge and a blunt stout spine or knob in the middle. The marginal plates (Fig. 27c) have a similar fringe of granules with one to three blunt spines in the middle. Grows to a large size up to 20 cm. radius of arms, and in life is a beautiful scarlet colour.

Pseudarchaster parelii. This species is by no means as distinctive in shape as the previous two. In the region north of Norway is not likely to be confused with any other species, but at Iceland and elsewhere it may be found with species from which it is not so easily separated. Readers are therefore referred to the keys of Mortensen (1927) or Koehler (1924). The radius of the arms is three or four times that of the disk. The upper surface is patterned in the same way as *Ceramaster*, with hexagonal groups of flat-topped granules. The upper marginal plates are covered completely with similar granules, while the lower marginals have some small spines in their mid-line. Plates on the lower surface covered with small spines with a few larger ones intermingle. In life this starfish is rigid like *Ceramaster* and is red-brown in colour. Reaches a maximum size of about 20 cm. radius of arm.

5. *Lophaster furcifer* (Düben and Koren)

This species, whose genus is closely related to *Solaster*, has a very characteristic appearance (Fig. 28a). Its upper surface is covered by prominent paxillae which are

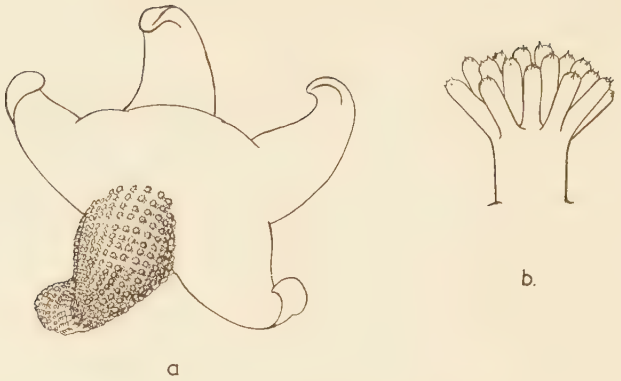


FIG. 28

(a) *Lophaster furcifer* (about one-third natural size), (b) single dorsal paxilla (×10).

arranged more or less in series. Each paxilla is about 2 mm. in height (often more), ar consists of a stout stalk for about half the total height, with a crown of 20 or more sho spines, which give it an overall diameter of about 2 mm. (Fig. 28b). There are two margin rows of extra large paxillae. According to Koehler (1924) it reaches a diameter of 28 cm but it is usually about half that size. In life the skin of the upper surface is brick-red colour, with the paxillae somewhat paler.

7. *Hymenaster pellucidus* Thomson

There is no other species in the area which can be confused with *Hymenaster pellucidu* It is a very delicate form, more or less pentagonal in shape. The five arms are joined by thin membrane supported by fine spines which can be seen through the membrane. Th paxillae on the upper surface have six or seven slender spines which support the supr dorsal membrane covering the whole upper surface. The whole animal is translucent even transparent and is usually a delicate rose colour in life. It attains a size of about 8 cm diameter. The young are brooded in the cavity under the supra-dorsal membrane.

8. *Gorgonocephalus arcticus* Leach, *G. eucnemis* (Müller and Troschel), *G. lamarcki* (Müll and Troschel) *and G. caput-medusae* (L.)

The genus is recognised by the character of the five arms, which bifurcate close to th disk and each branch itself bifurcates repeatedly. The various species are separated b the following key (after Mortensen, 1927):

1 Disk wholly covered by coarse or fine spines; those on the radial ribs not special prominent . . . 2.
Disk naked, only the radial ribs with some large spines, or with smooth rounde grains. . . . 3.

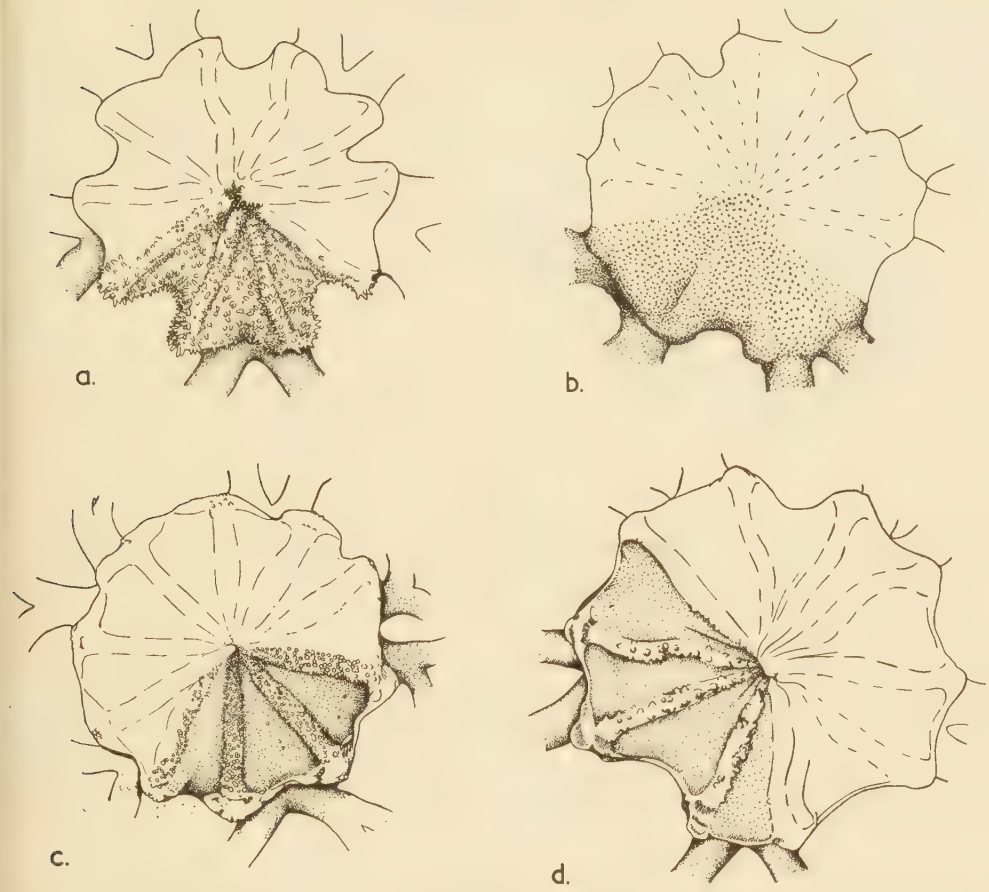
2 Disk with rather coarse spines or tubercles; arm spines smooth, curved . . . *G. capu medusae* (Fig. 29a).
Disk closely covered with fine spinelets, almost velvety in appearance; arm spine compressed, coarsely pectinate . . . *G. lamarcki* (Fig. 29b).

3 Radial ribs with rounded grains . . . *G. eucnemis* (Fig. 29c).
Radial ribs with larger spines . . . *G. arcticus* (Fig. 29d).

G. caput-medusae is included in the key because it is known from the Norwegian coas as far as Trondhjem Fjord, and may perhaps have spread further north.

All the species grow to 9 or 10 cm. diameter of disk, but *G. lamarcki* has only been foun in the Area up to about 6 cm. in diameter. Specimens smaller than 2 cm. diameter of dis are extremely difficult to identify as the character of the disk is not always apparent in suc young stages.

In life they all are various shades of brown in colour. *G. caput-medusae* is reddish- c



IG. 29. *Dorsal views of the disks of the North Atlantic species of* Gorgonocephalus (*each* about half natural size).

(a) *G. caput-medusae*, (b) *G. lamarcki*, (c) *G. eucnemis*, (d) *G. arcticus*.

ellowish-brown and sometimes very pale. *G. lamarcki* tends to be a slightly reddish-brown, ften with some maroon markings. *G. eucnemis* and *G. arcticus* are both orange-brown, ith the radial ribs pale brown, almost white.

. *Ophiopleura borealis* Danielssen and Koren

This magnificent Ophiuroid (Fig. 30a) has a very characteristic appearance, so that cannot easily be confused with any other species. It is recognised by its large size and lmost uniform pale colouring, usually orange or reddish. Two other Ophiuroids *Ophiura arsi* and *Ophiocten sericeum*, which may be found with *Ophiopleura borealis*, are distinguished by their mottled colouring of brown, white and sometimes red and black. In ddition, the disk of *Ophiopleura* is covered by a thin skin, and the scales are hardly pparent, except in dried specimens, whereas the scales of *Ophiura* and *Ophiocten* are aked. Other differences are to be found in the shapes of the mouth shields and the ventral rm plates (Compare Fig. 30a, b. c. d and e.). *Ophiopleura borealis* attains a size of 45 mm. iameter of disk, *Ophiura sarsi* about 35 mm. diameter and *Ophiocten sericeum* 18 mm. iameter.

0. *Geodia barretti* Bowerbank

It is impossible to give here full notes for the identification of *Geodia barretti*, as the iagnoses of the various species is extremely difficult owing to the inadequacy of many of he original descriptions. Frontispiece gives some idea of the size and shape of these

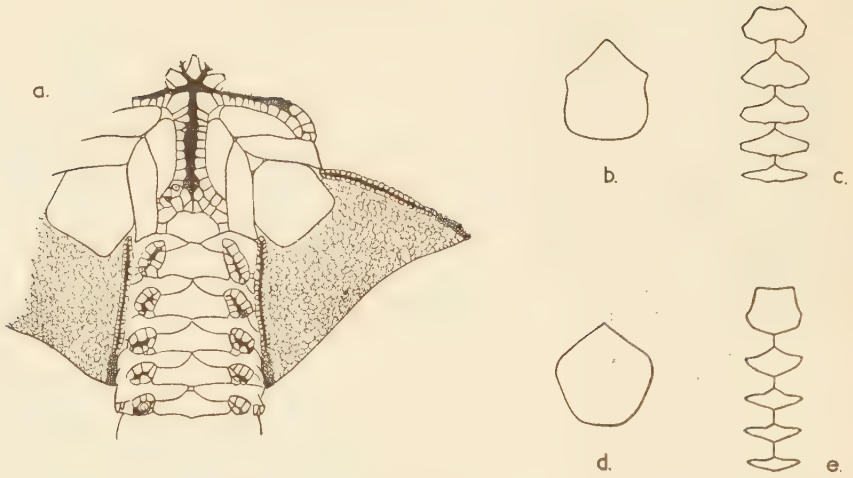


FIG. 30

(a) *Ophiopleura borealis*, part of the oral surface of the disk (approximately 1½ times natural size).
(b, c) *Ophiura sarsi*, (b) mouth shield, (c) innermost ventral arm-plates.
(d, e) *Ophiocten sericeum*, (d) mouth shield, (e) innermost ventral arm-plates.

sponges, which are of a sulphur-yellow colour. Two other large sponges, *Thenea murica* (Bowerbank) and *Isops phloegrei* Sollas, are frequently trawled up with *Geodia*. Lar specimens of the former may be distinguished by the bright yellow-green patches on t surface, while the latter is usually pale grey and is a more or less regular pudding-ba shape. These two species not only have the same distribution as *Geodia*, but also sha with it the trawlermen's nickname of 'duff'.

APPENDIX 2

TABLES OF PAST OCCURRENCES OF SELECTED SPECIES

The references from which these tables are compiled are all given in Section III, 'Previo work on the benthos of the Area'. Table 1 covers the period 1878–1914, while Table covers the Norwegian fishery cruises from 1923 until 1931.

The nomenclature used in these tables as well as those of recent occurrences (Append 3) conform as far as possible with those used in the *Zoology of Iceland* (Einarsson, 194 and Stephensen, 1939), to facilitate comparison with other parts of the North Atlanti Where these names differ from those used in earlier works, the synonyms are given in th appropriate paragraphs of Section IV.

APPENDIX 3

TABLES OF RECENT OCCURRENCES

These tables include the records from the ERNEST HOLT cruises of all the species of Echin derms and Decapod Crustacea found in the collections made during the period 1949–5 except for those from two cruises to Greenland in 1952. It is felt that records of all speci may conveniently be included here because many of them may be of considerable value other workers on benthos, but are unlikely to be used for any future publication from th laboratory.

For Cruises V/1954 and IV/1955 only records of the selected indicator species are given because the collections of other species made during those cruises have not been fully worked up.

Positions of stations for the years 1949 and 1950, together with bottom temperature data and details of gear used, are published in Graham *et al.*, 1954. It is hoped that a similar paper giving cruise data for the other years will be published soon. Temperature and other hydrographic data for the years 1949, 1950, 1951 and 1952 are published in the *Bulletins Hydrographiques* for those years.

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18447. Wt.2739. 6028. K.5. 6/57. S.P. & S. G.9-8-8.

PPENDIX 2. TABLE 1. PAST OCCURRENCES IN THE AREA. 1878–1914

Cruise	*Vøringen*, 1878										*Princesse-Alice*, 1898, 1899											
ion Number	280	290	315	323	336	338	359	363	370	374	960	976	997	1012	1070	16	17	26	28	33	39	
pth (fathoms)	35	191	180	223	70	146	416	260	109	60	215	102	56	235	95	98	38	79 –98	20 –76	104	63	
tom Temperature °C.	1·1	3·5	2·5	1·5	0·4	–1·1	0·8	1·1	1·1	0·7	–	–	–	–	–	–	–	–	–	–	–	
iometra glacialis	–	–	–	–	+	–	+	+	+	+	–	+	+	+	+	–	–	+	+	–	+	
iometra prolixa	–	–	–	–	–	–	+	+	–	–	–	–	–	+	–	–	–	–	–	–	–	
amaster granularis	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	
udarchaster parelii	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	
pasteria phrygiana	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
menaster pellucidus	–	–	–	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	–	–	–	
haster furcifer	–	–	–	–	–	–	+	–	–	–	–	–	–	+	–	–	–	–	–	–	+	
rgonocephalus arcticus	–	–	–	–	–	–	–	+	–	–	–	+	–	+	–	+	–	–	–	+	–	
rgonocephalus eucnemis	–	–	+	+	+	–	+	+	+	–	–	–	–	+	+	–	+	–	–	–	+	
hodes maia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
erocrangon boreas	+	–	–	–	–	–	–	–	+	–	–	–	–	–	–	+	–	+	–	–	–	
erocrangon ferox	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	
binea sarsi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
binea septemcarinata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Position Lat. ° ′N.	74 10	72 27	74 53	72 53	76 19	76 19	78 02	80 03	78 48	Advent Bay, Spitsb.	72 37	76 45	78 22	80 01	79 18	75 40	76 25	Green Harbour, Spitsb.	79 00	Sassen Bay, Isfjord	76 58	
Position Long. ° ′E.	18 51	20 51	15 55	21 51	15 42	18 01	9 25	8 28	8 37		20 00	23 20	17 10	10 51	10 31	17 30	16 15		11 00		13 20	

PPENDIX 2. TABLE 2. PAST OCCURRENCES IN THE AREA, 1923–1931

Cruise	*Blaafjeld*, 1923													*Tovik*, 1924									
ation Number	3	5	13	20	34	39	43	49	50	51	52	91	99	35	56	79	88	90	91	10	14	2(
epth (fathoms)	111 –118	131 –137	73 –109	–	78 –182	22 –130	120 –138	116 –161	132 –164	115 –140	127 –144	93	–	115 –133	105	85	105 –113	–	83	101 –125	82	122 –13
ottom Temperature °C.	–	–	2·2	–	2·6	1·6	–	–	–	2·6	–	0·9	–	2·0	0·8	–	–	–	1·5	–	1·2	4
eliometra glacialis	–	–	–	–	–	–		–	–	+	+	–	–	–	–	–	+	–	–	+	+	
liometra prolixa	–	–	–	–	–	+	–	+	+	–	+	–	–	+	–	+	–	–	–	–	–	
ramaster granularis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
eudarchaster parelii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
ippasteria phrygiana	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
ymenaster pellucidus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
phaster furcifer	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
orgonocephalus arcticus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	
orgonocephalus eucnemis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
thodes maia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
lerocrangon boreas	–	–	+	+	–	–	–	–	–	–	–	+	+	–	–	+	–	+	+	–	+	
lerocrangon ferox	+	+	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	
binea sarsi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
binea septemcarinata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	
Position Lat. ° ′N.	77 43	77 42	78 42	Isfjord	79 53	78 57	76 58	76 35	76 56	76 58	77 41	76 43	Green Harbour	73 47	76 05	76 37	77 48	Green Harbour	Green Harbour	77 44	78 05	
Position Long. ° ′E.	10 51	10 44	9 53		10 39	10 20	12 45	13 43	12 50	12 35	11 20	29 12		18 20	26 47	28 16	10 55			11 45	14 11	

| | | |

ENDIX 3. TABLE 6. CRUSTACEA DECAPODA, 1952

Cruise Number	I						III					IV	
Number	21	22	23	24	25	76	33	44	46	47	51	82	104
(fathoms)	33	36	50	54	76	147	140	110	164	194	110	70	64
Temperature °C.	0·20	−0·32	1·82	1·60	–	5·36	1·31	0·80	1·16	0·76	1·38	1·19	–
raneus	–	+	–	–	+	–	–	–	–	–	+	+	–
oarctatus	–	–	–	–	–	+	–	–	–	–	–	–	–
a sarsi	–	–	–	–	–	+	–	–	–	–	–	–	–
a tenuimana	–	–	–	–	–	–	–	–	–	–	–	–	–
urus pubescens	+	+	+	+	+	+	–	–	+	–	+	–	+
es maia	–	–	–	–	–	–	+	–	–	–	–	–	–
rangon boreas	–	–	–	–	–	–	–	–	–	–	–	–	–
rangon ferox	–	–	–	–	–	–	–	–	–	–	–	–	–
hilus norvegicus	–	–	–	–	–	–	–	–	–	–	–	–	–
a sarsi	–	–	+	–	–	+	–	–	–	–	–	–	–
a septemcarinata	+	+	–	+	–	–	–	+	–	–	–	–	–
tocaris gaimardi	–	–	–	–	–	–	–	–	–	–	–	–	–
tocaris spinus	+	–	–	–	–	–	–	–	–	–	–	–	–
tocaris polaris	–	–	–	–	–	+	–	+	–	–	–	–	–
lus borealis	–	–	+	+	+	–	–	+	+	+	–	+	–
									*		*		

tows at each station. Depth given is that of position of hauling of 1st tow, and shooting of 2nd.

PENDIX 3. TABLE 7. CRUSTACEA DECAPODA, 1953

Cruise Number	III						IV				V								
n Number	18	21	22	23	33	61	10	23	36	37	15	16	28	32	40	44	47	51	52
(fathoms)	200	200	200	200	70	200	90	202	98	90	125	130	165	92	210	160	128	155	130
n Temperature °C.	–	–	–	–	–	–	−1·58	–	0·32	0·41	0·92	0·94	0·80	0·04	−0·12	0·32	−0·24	−0·74	−0·97
araneus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
coarctatus	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–
da sarsi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
da tenuimana	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
urus pubescens	–	–	–	–	–	–	+	–	–	–	–	+	+	–	–	–	–	–	–
des maia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
crangon boreas	–	–	–	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–
crangon ferox	–	–	–	–	–	–	+	–	+	+	–	–	–	–	–	–	–	–	–
philus norvegicus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ea sarsi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ea septemcarinata	+	+	+	–	–	–	+	+	+	+	–	–	–	–	–	+	+	+	+
ntocaris gaimardi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ntocaris spinus	–	–	–	–	–	–	+	–		+	–	–	–	–	–	–	–	–	–
ntocaris polaris	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–	+	–	–	–
alus borealis	+	+	+	+	–	+	+		+	–	+	+	+	+	+	+	+	+	+

Cruise Number	VII																			
n Number	13	14	16	18	19	20	21	23	29	30	31	32	33	34	35	36	37	38	40	41
(fathoms)	136	125	100	104	90	90	78	68	130	90	115	115	124	125	152	110	90	80	130	123
m Temperature °C.	0·40	0·42	0·34	0·78	0·77	0·73	0·22	−0·43	0·52	–	0·91	0·95	0·96	0·77	–	0·86	0·32	0·40	1·20	1·16
araneus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
coarctatus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
da sarsi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
da tenuimana	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
urus pubescens	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
des maia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
crangon boreas	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+	+	–	–
crangon ferox	+	–	+	+	+	+	+	+	+	?	+	–	+	–	–	–	+	–	–	–
philus norvegicus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ea sarsi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ea septemcarinata	–	–	–	+	+	+	+	–	+	+	+	–	+	+	+	+	+	+	–	+
ntocaris gaimardi	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ntocaris spinus	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
ntocaris polaris	–	–	+	–	–	–	–	–	+	–	–	+	–	–	–	–	+	+	–	+
alus borealis	+	+	+	+	+	+	+	–	+	+	+	–	+	+	+	+	+	–	+	+

						VI																		
53	58	61	68	70	72	13	16	28	31	32	34	41	42	44	45	46	47	48	51	52	53	63	65
20	77	80	104	88	95	78	100	80	156	160	84	112	116	130	133	114	100	146	128	114	115	90	90
·26	−1·06	75	0·64	0·36	0·68	−	−	−	0·28	−	−0·30	−0·02	−0·11	−0·47	−0·38	−0·33	−0·68	0·05	−0·08	0·33	0·46	−	−
−	−		−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	
−	−		−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	−		−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	−		−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	+		−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	−		−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	−		−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
+	+		−	−	−	+	−	−	−	+	−	−	+	+	+	+	+	+	−	−	−	−	
−	−		−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	−		−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
+	+		+	+	+	+	+	+	+	−	−	+	+	+	−	+	+	+	−	−	+	−	
−	−		−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	−		+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	
−	+		+	−	+	+	−	−	+	+	−	−	−	+	−	−	−	+	−	+	+	−	−
+	+		+	+	+	−	+	−	+	+	+	+	−	−	−	+	−	+	+	−	−	−	−

											VIII		
42	48	0	53	54	55	56	59	60	61	63	38	39	75
112	158	2	115	118	125	90	120	82	90	90	145	150	130
·66	−0·06	−28	0·93	1·02	−	0·88	1·18	1·28	−	−	0·46	−	−1·57
−	−		−	−	−	−	−	+	−	−	−	+	−
−	−		−	−	−	−	+	−	−	−	−	−	−
−	−		−	−	−	−	−	−	−	−	−	−	−
−	−		−	−	−	−	−	−	−	−	−	−	−
−	−		−	−	−	−	−	−	−	−	−	−	−
−	−		−	−	−	−	−	−	−	−	−	−	−
−	−		−	−	−	−	−	−	−	−	−	−	−
−	−		−	−	−	−	−	−	−	−	−	+	−
−	−		−	−	−	−	−	−	−	−	−	−	−
−	−		−	−	−	−	−	−	−	−	−	−	−
+	+		−	+	+	+	+	+	+	+	+	−	+
−	−		−	−	−	−	−	−	−	−	−	−	−
−	−		−	−	−	−	−	−	+	−	−	−	−
+	−		+	−	−	+	−	+	+	+	−	−	−
+	+		+	+	+	+	+	−	+	+	+	−	−
											*		*

* Bottom temp. at start of trawl haul.

PENDIX 3. TABLE 10. ECHINODERMA I, CRINOIDEA AND ASTEROID

Cruise Number	I				II		III					IV								
n Number	25	27	37	40	8	11	42	43	46	55	59	20	21	24	26	28	32	36	41	44
. (fathoms)	185	192	90	70	135	168	116	160	180	124	145	160	130	105	170	110	176	90	106	205
n Temperature °C.	3·22	3·83	–	6·77	1·92	2·25	–	0·80	1·04	0·92	0·82	2·97	2·90	0·74	1·32	0·52	0·86	−0·46	−0·26	1·05
netra glacialis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–
discus crispatus	–	–	–	–	–	–	+	–	+	+	+	–	–	–	–	+	+	–	+	+
otychaster arcticus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ster tenuispinus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	+	–
aster granularis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
archaster parelii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
asteria phrygiana	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
niomorpha hispida	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
niomorpha tumida	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+
aster mirabilis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ster militaris	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	–	+	–
ster pulvillus	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	+	–
ster obscurus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	–
enaster pellucidus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
thraster hispidus	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–
ter papposus	–	–	–	–	–	–	–	–	+	–	–	+	–	–	–	–	–	–	+	–
ter endeca	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
ter syrtensis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	–
aster furcifer	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–
icia sanguinolenta	–	–	+	+	+	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–
ellaster typicus	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–
terias lincki	–	–	–	–	–	–	–	–	–	–	+	–	–	+	+	+	+	+	+	–
erias panopla	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+	+	–	–
asterias mulleri	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
hanasterias albula	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

PENDIX 3. TABLE 11.

CHINODERMA I, CRINOIDEA AND ASTEROIDEA, 1952

Cruise Number	I			III							IV		
ion Number	23	24	76	33	34	44	46	47	51	53	36	67	104
th (fathoms)	50	54	147	140	162	110	164	194	110	138	70	85	64
om Temperature °C.	1·82	1·60	5·36	1·31	2·75	0·80	1·16	0·76	1·38	3·63	1·07	2·44	–
ometra glacialis	–	–	–	–	–	–	–	–	–	–	–	–	–
odiscus crispatus	–	–	–	–	–	–	–	–	–	+	–	–	–
toptychaster arcticus	–	–	–	–	–	–	–	–	–	–	–	–	–
taster tenuispinus	–	–	–	–	–	+	+	+	–	+	–	–	–
master granularis	–	–	–	–	–	–	–	–	–	–	+	–	–
darchaster parelii	–	–	–	–	–	–	–	–	–	–	–	–	–
pasteria phrygiana	–	–	–	+	+	–	–	–	–	–	–	–	–
aniomorpha hispida	–	–	–	–	–	–	–	–	–	–	–	–	–
aniomorpha tumida	–	–	–	–	–	–	–	–	–	–	–	–	–
master mirabilis	–	–	–	–	–	–	–	–	–	–	–	–	–
raster militaris	–	–	–	–	–	–	–	–	–	–	–	–	–
raster pulvillus	–	–	–	–	–	–	–	–	–	–	–	–	–
raster obscurus	–	–	–	–	–	–	–	–	–	–	+	–	–
nenaster pellucidus	–	–	–	–	–	–	–	–	–	–	–	–	–
ethraster hispidus	–	–	–	–	–	–	–	–	–	–	–	–	–
aster papposus	–	–	–	–	–	–	–	–	–	–	+	+	–
aster endeca	–	–	–	–	–	–	–	–	–	–	–	–	–
aster syrtensis	–	–	–	–	–	–	–	–	–	–	+	–	–
haster furcifer	–	–	–	–	–	–	–	–	–	–	–	–	–
ricia sanguinolenta	–	+	+	–	–	+	–	–	–	–	–	–	–
licellaster typicus	–	–	–	–	–	–	–	–	–	–	–	–	+
asterias lincki	+	–	–	–	–	+	–	–	+	–	–	–	–
sterias panopla	–	–	–	–	–	+	–	–	+	–	–	–	–
tasterias mulleri	–	–	–	–	–	–	–	–	–	–	–	–	–
phanasterias albula	–	–	–	–	–	–	–	–	–	–	+	–	–

						V										VI							
47	90	52	–	54	56	11	17	20	65	66	69	71	72	76	78	110	25	31	32	33	35	44	50	51
120	90	102	–	115	170	88	92	80	72	52	70	90	80	25	50	95	100	100	98	76	82	120	110	105
–	0·00	1·[illegible]	–	·04	1·26	0·71	–	–	4·52	3·28	2·80	1·70	1·64	–	3·52	0·40	4·49	4·52	5·42	3·41	3·60	2·75	5·11	3·30
–	–	–	–	–	–	–	–	+	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–
+	–			–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–				–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
+	–			–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	+	+	–	–	–	–	+	+	–	–	–	–	–	+	–	+	–	–	–	–	+	–	–
+	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	+	–	–	+	–	+	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
–	+	–	–	–	–	–	+	–	–	+	–	+	–	–	–	+	–	–	–	+	–	–	–	–
–	+	–	–	–	–	–	–	+	–	+	–	–	–	–	–	–	–	+	–	+	–	–	–	–
–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
+	+	–	+	–	–	–	–	–	–	–	+	–	–	–	–	–	+	–	+	–	+	+	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
+	+	–	+	+	–	–	+	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	+
–	–	–	–	–	–	–	–	–	–	+	–	–	+	+	–	–	–	–	–	–	–	–	–	–
–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

ENDIX 3. TABLE 14. ECHINODERMA II, OPHIUROIDEA, ECHINOIDEA

Cruise Number	I			III			IV	V												
Number	49	61	81	44	50	75	18	11	12	14	27	31	33	35	38	44	50	52	54	55	57
(fathoms)	57	64	110	250	105	200	66	75	86	155	120	100	100	117	150	206	116	118	99	68	80
Temperature °C.	1·82	1·82	2·32	4·03	1·25	4·54	1·26	1·61	2·65	3·08	3·02	–	3·39	3·36	2·66	2·58	2·67	2·78	2·38	1·24	2·42
ocephalus arcticus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ocephalus eucnemis	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–
ocephalus lamarcki	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
colex glacialis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
colex purpureus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
antha bidentata	–	–	–	+	–	+	–	+	–	–	+	–	+	–	+	+	+	+	+	–	+
us arcticus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
holis aculeata	+	–	+	+	+	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+
ura sundevalli	–	–	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
pholis squamata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
a robusta	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–
a sarsi	–	–	–			–	–	+	+	–	–	–	–	–	–	–	–	–	+	+	+
ten sericeum	–	–					–	–	–	–	–	–			+	–	–	–	–	–	–
pleura borealis	–	–	–	–	–	–	–	–	–	–	–	–	–	–		–	–	–	–	–	–
s esculentus	–	–	–		–	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–
ylocentrotus droebachiensis	–	+	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	+	+	–
ichopus tremulus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
naria frondosa	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–
cucumis hispida	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
nodactyla commune	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
phantapus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
fabricii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ostoma arcticum thomsonii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
trochus rinki	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

PENDIX 3. TABLE 15. ECHINODERMA II, OPHIUROIDEA, ECHINOIDE

Cruise Number	I						II			III											
n Number	25	26	35	37	40	42	8	11	22	40	42	43	46	55	59	60	20	21	22	23	24
n (fathoms)	185	195	105	90	70	90	135	168	120	148	116	160	180	124	145	135	160	130	70	77	105
m Temperature °C.	3·22	3·34	6·83	-	6·77	–	1·92	2·25	2·10	1·46	–	0·80	1·04	0·92	0·82	–	2·97	2·90	1·10	2·02	0·74
mocephalus arcticus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
mocephalus eucnemis	–	–	–	–		–	–	–	–	–	–	–	+	–	–	–	–	–	+	–	–
mocephalus lamarcki	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
oscolex glacialis	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–
oscolex purpureus	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
icantha bidentata	+	+	–	–	–	–	+	–	–	–	+	–	–	+	+	–	+	+	–	–	–
ppus arcticus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
pholis aculeata	–	–	–	+	–	–	+	+	+	+	·	+	+	–	+	+	+	–	+	+	+
iura sundevalli	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ipholis squamata	–	–	–	–	–	–	–	–	–	–	–	–	–	-	–	–	–	–	–	–	–
ra robusta	–	–	–	–	–	–	–	–	+	–	–	–	–	–	+	–	–	–	–	–	–
ra sarsi	–	–	–	–	–	–	+	–	–	–	–	-	–	-	–	–	–	–	+	–	+
cten sericeum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
pleura borealis	–	–	–	–	–	–	–	–	–	–	–	-	–	–	–	–	–	–	–	–	–
us esculentus	–	–	+	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
gylocentrotus droebachiensis	–	–	–	–	·	–	–	-	–	–	–	–	–	–	–	–	–	+	+	+	–
tichopus tremulus	–	–	–	–	–	–	–	–	–	–	-	–	–	–	–	–	–	–	–	–	–
naria frondosa	–	–	–	–	–	-	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
ocucumis hispida	–	–	–	–	–	–	–	–	–	–	–	-	–	–	–	–	–	–	–	–	–
nodactyla commune	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
s phantapus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
s fabricii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ostoma arcticum thomsonii	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–
otrochus rinki	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

ANHOLOTHURIOIDEA, 1950

					VII															VIII		
60	68	72	74	80	49	52	53	54	56	59	60	61	63	65	67	71	72	88	101	111	39	42	43
150	185	68	126	110	78	90	74	78	90	82	52	36	30	44	44	56	65	78	106	148	66	106	130
2·86	−6	2·32	1·06	2·34	3·00	3·30	4·45	3·87	3·74	3·74	2·08	2·35	1·60	0·14	2·08	0·49	0·73	4·24	3·42	3·80	3·75	2·62	2·53	3·
−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	
−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	
−	·	−	−	−	−	−	−	−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	+	+	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
+	+	+	−	+	+	+	+	+	+	+	−	+	+	−	−	−	−	+	+	−	+	+	+	
−	·	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	+	−	−	−	+	−	+	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	
−	·	+	+	−	+	+	−	+	−	+	−	−	−	−	−	−	+	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	+	−	−	−	+	−	+	-	+	+	+	+	+	+	−	−	−	−	−	+	+	+	
·	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	-	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	+	+	+	+	+	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	
−	·	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	

ANOLOTHURIOIDEA, 1951

			IV											V											
25	26	28	32	36	41	44	47	50	51	53	54	56	11	17	20	65	66	69	71	72	76	77	78	108
105	170	110	176	90	106	205	120	90	92	84	115	170	88	92	80	72	52	70	90	80	25	35	50	120
1·05	1·32	0·52	0·86	−0·46	−0·26	1·05	−	0·00	−	1·00	1·04	1·26	0·71	−	−	4·52	3·28	2·80	1·70	1·64	−	3·34	3·52	−
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
−	−	−	−	+	+	−	−	+	−	−	−	−	−	−	−	+	+	+	−	−	−	+	−	−
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
−	−	+	−	+	+	+	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
−	+	+	+	+	+	+	+	−	−	−	+	+	−	−	+	+	+	+	−	−	−	−	−	+
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
+	−	+	+	+	−	−	+	+	+	+	+	+	−	−	−	−	+	+	−	−	−	+	+	−
−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
−	−	+	−	−	+	−	+	−	−	−	+	−	−	−	−	−	−	−	+	−	−	−	−	−
−	+	+	+	−	+	−	+	−	−	+	+	+	+	−	−	−	+	−	−	−	−	−	+	−
−	−	+	+	−	−	−	+	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
+	−	+	+	+	+	−	+	+	+	−	+	−	−	+	+	−	+	+	+	+	+	+	+	+
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	+	+	−	−
−	−	−	+	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
−	−	+	+	−	−	+	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
−	+	−	−	−	+	+	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−

APPENDIX 3. TABLE 18. *GEODIA BARRETTI* BOWERBANK, 1949–53

1949 *Cruise Number*	I		II	IV											V				VIII
Station Number	8	14	9	9	11	24	25	27	28	35	36	53	55	56	22	25	36	94	16
Depth (fathoms)	130	115	104	216	206	264	240	230	244	212	205	150	154	150	160	155	174	134	85
Bottom Temperature °C.	4·23	6·70	6·94	2·19	1·26	2·75	4·03	2·91	1·99	2·02	2·03	4·15	–	–	2·92	2·76	1·87	4·23	4·88

1950 *Cruise Number*	III					V									VII					
Station Number	44	45	46	61	75	14	21	25	27	36	44	46	60	68	84	108	109	110	111	
Depth (fathoms)	250	180	140	227	200	155	145	140	120	132	206	149	150	125	98	154	144	144	148	
Bottom Temperature °C.	4·03	4·40	2·76	2·26	4·54	3·08	3·28	4·16	3·02	2·94	2·58	2·65	2·86	2·86	3·40	4·37	3·45	3·32	3·80	4

1951 *Cruise Number*	I											II						IV		
Station Number	25	26	27	28	30	31	32	34	35	40	42	9	11	14	15	26	27	20	21	
Depth (fathoms)	185	195	192	196	180	195	180	105	105	70	90	158	168	115	115	165	128	160	130	18
Bottom Temperature °C.	3·22	3·34	–	3·18	2·38	2·14	2·66	6·69	6·83	6·77	–	1·76	2·25	1·70	1·12	3·44	1·75	2·97	2·90	1·2

1952 *Cruise Number*	I	III	1953	III			VII	
Station Number	76	34		39	49	53	58	59
Depth (fathoms)	147	162		95	168	172	124	120
Bottom Temperature °C.	5·36	2·75		–	–	–	1·34	1·18

APPENDIX 3. TABLE 19. SELECTED INDICATOR SPECIES, V/1954

1954 *Cruise Number*	V																			
Station Number	37	39	40	50	51	60	70	71	72	73	81	91	92	103	104	106	107	108	109	124
Depth (fathoms)	125	86	72	60	94	140	100	100	95	100	90	90	80	100	110	44	30	80	35	105
Bottom Temperature °C.	4·56	3·96	3·95	4·00	3·72	3·88	5·26	–	4·34	–	–	3·70	–	–	3·52	3·34	–	3·38	3·70	1·16
Heliometra glacialis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
Ceramaster granularis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pseudarchaster parelii	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hippasteria phrygiana	–	–	+	+	+	+	–	–	–	+	–	+	+	–	–	–	–	–	–	–
Hymenaster pellucidus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lophaster furcifer	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gorgonocephalus arcticus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+
Gorgonocephalus eucnemis	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	+	+	–
Gorgonocephalus lamarcki	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ophiopleura borealis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lithodes maia	–	–	–	–	–	–	+	–	+	+	–	+	+	+	+	+	–	–	–	–
Sclerocrangon ferox	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sclerocrangon boreas	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
Sabinea sarsi	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–
Sabinea septemcarinata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Geodia barretti	+	–	–	–	–	–	–	+	+	–	+	+	+	–	–	–	–	–	–	–

	IX
20	33 52
120	125 57
2·98	– 30

	IX				
80	81	1 131	164	165	168
115	115	1 110	157	148	112
·35	4·53	2·3·15	2·57	3·67	4·02

		VI						VII						
27	56	450	52	62	84	85	87	43	46	47	49	50	51	52
30	170	1110	105	100	100	110	75	163	145	130	133	128	135	143
24	1·26	5·311	5·24	3·66	3·94	4·57	4·52	5·12	5·72	5·72	4·66	4·83	4·94	4·62

132	134
140	100
1·82	3·54
+	+
–	–
–	–
–	–
–	–
–	–
+	–
+	–
–	–
–	–
–	–
–	–
–	–
–	–
–	–

APPENDIX 3. TABLE 20. SELECTED INDICATOR SPECI

1955	*Cruise*	IV														
Station Number		17	18	19	28	29	30	31	32	33	34	35	48	49	50	5
Depth (fathoms)		95	130	110	85	85	105	115	130	140	145	130	190	170	128	9
Bottom Temperature °C.		1·94	1·90	2·25	0·96	–0·09	0·50	1·58	2·13	2·32	–	2·26	3·68	3·81	2·70	3·0
Heliometra glacialis		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Ceramaster granularis		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pseudarchaster parelii		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Hippasteria phrygiana		–	–	–	–	+	–	+	–	–	–	–	+	+	–	+
Hymenaster pellucidus		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lophaster furcifer		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gorgonocephalus arcticus		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gorgonocephalus eucnemis		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Gorgonocephalus lamarcki		–	–	–	–	–	–	+	–	–	–	+	–	–	–	–
Ophiopleura borealis		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lithodes maia		+	–	–	–	–	+	–	–	–	+	–	–	+	–	–
Sclerocrangon boreas		–	–	–	–	–	+	–	+	–	–	–	–	–	–	–
Sclerocrangon ferox		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sabinea sarsi		–	+	+	–	–	+	–	+	–	–	–	–	–	–	–
Sabinea septemcarinata		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Geodia barretti		–	–	–	+	–	–	+	–	+	+	+	+	–	+	–

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